THE MAGAZINE OF VISUAL COMPUTING

NUMBER THIRTY-THREE/4.95

FALL 1995

IRIS universe

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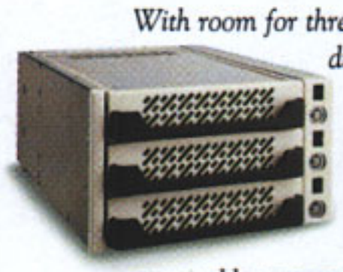
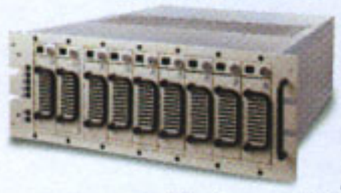
The DE100™ is a removable disk/tape subsystem that allows you to easily remove, transfer, and store data. It's compatible with an extensive variety of standard SCSI or IDE/EIDE drives.



With room for three 1" SCSI disk or tape drives, the DS300 model is the most compact removable storage subsystem available on the market today.



The DS500™ is an external rack mount that houses nine half-height bays, allows users to integrate any SCSI peripheral combination, and includes up to two 300-watt power supplies.

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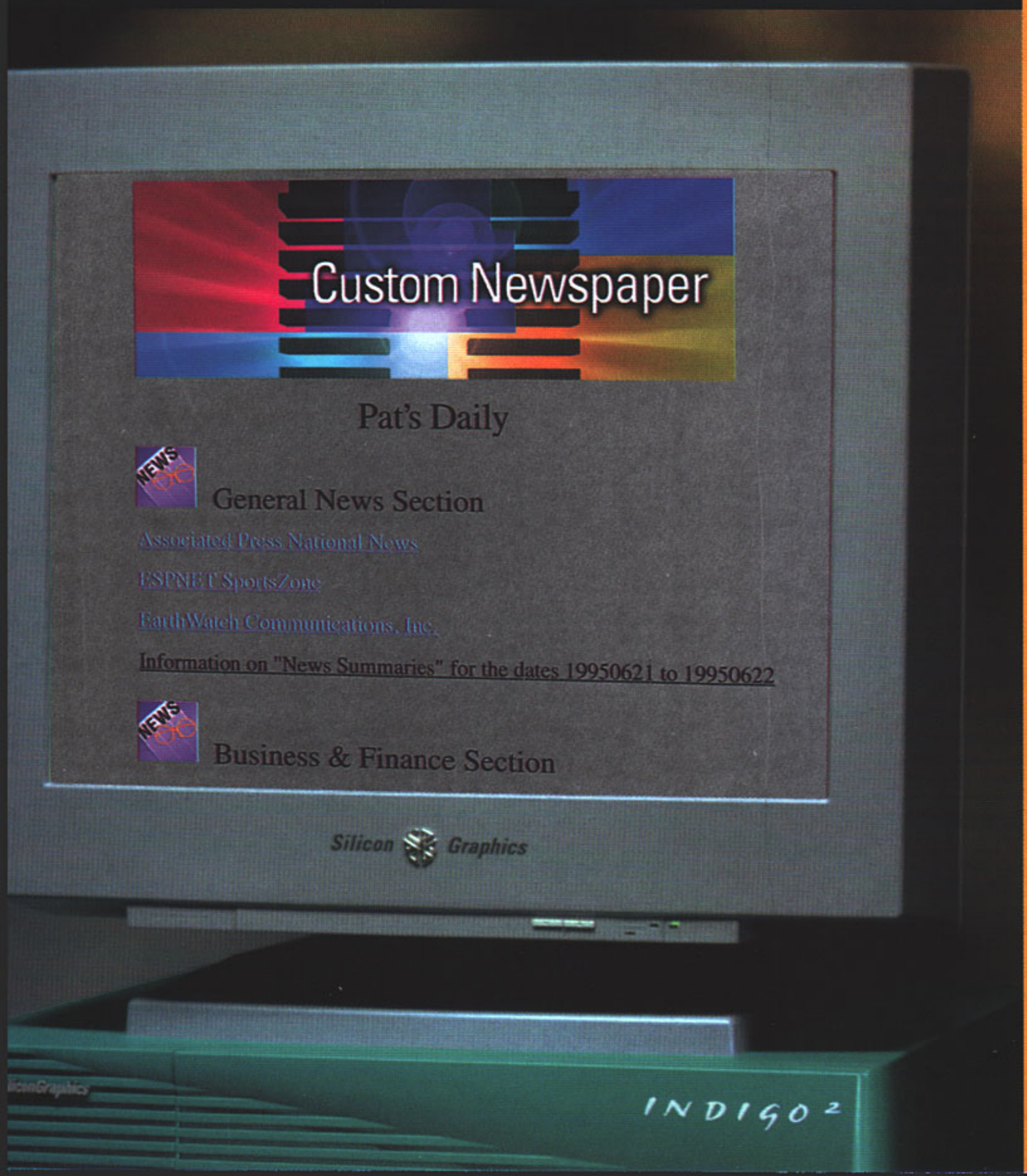

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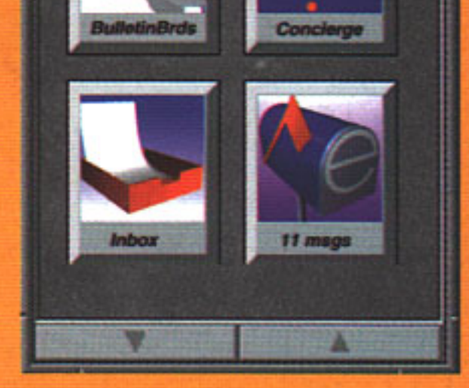

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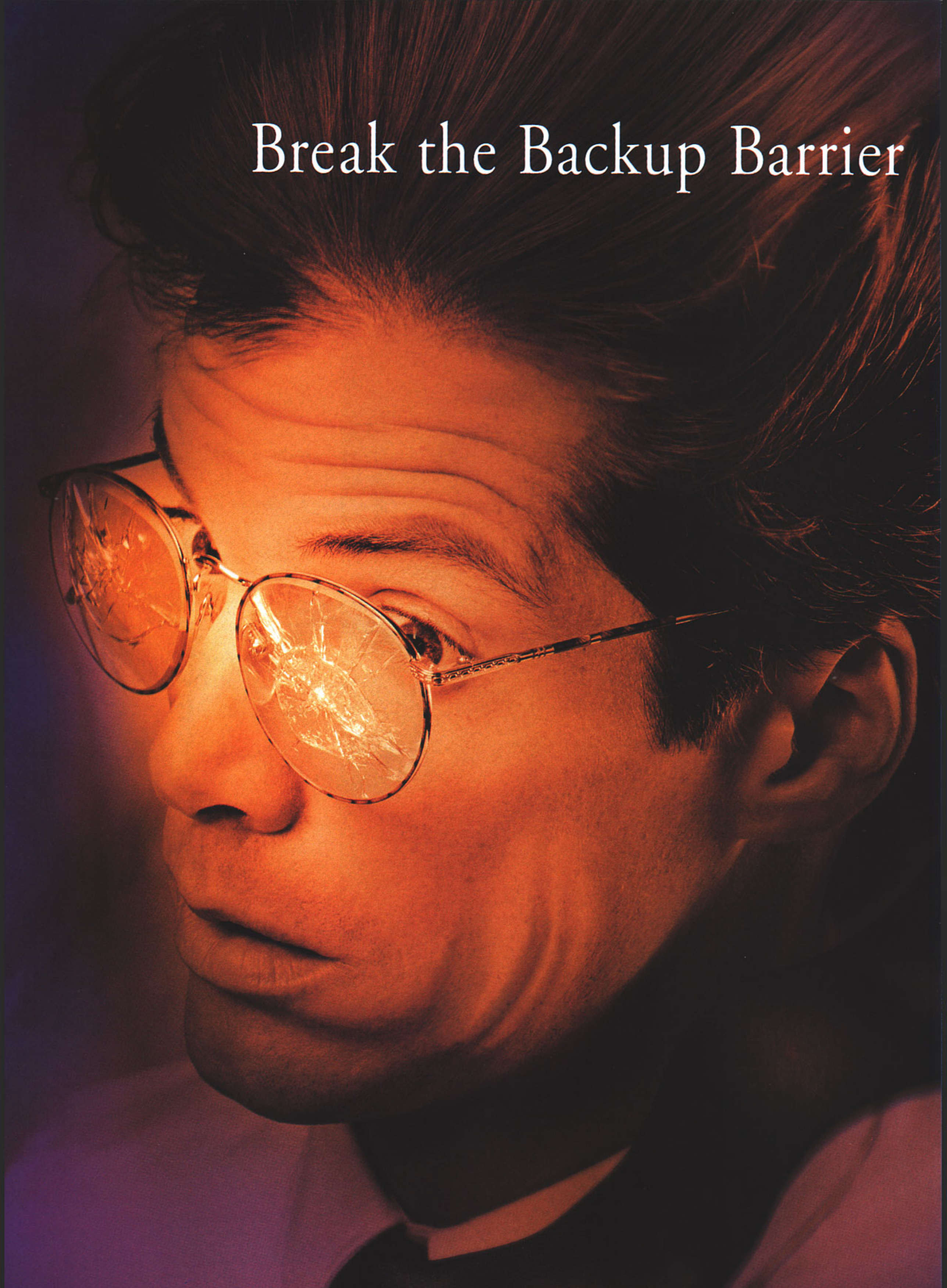

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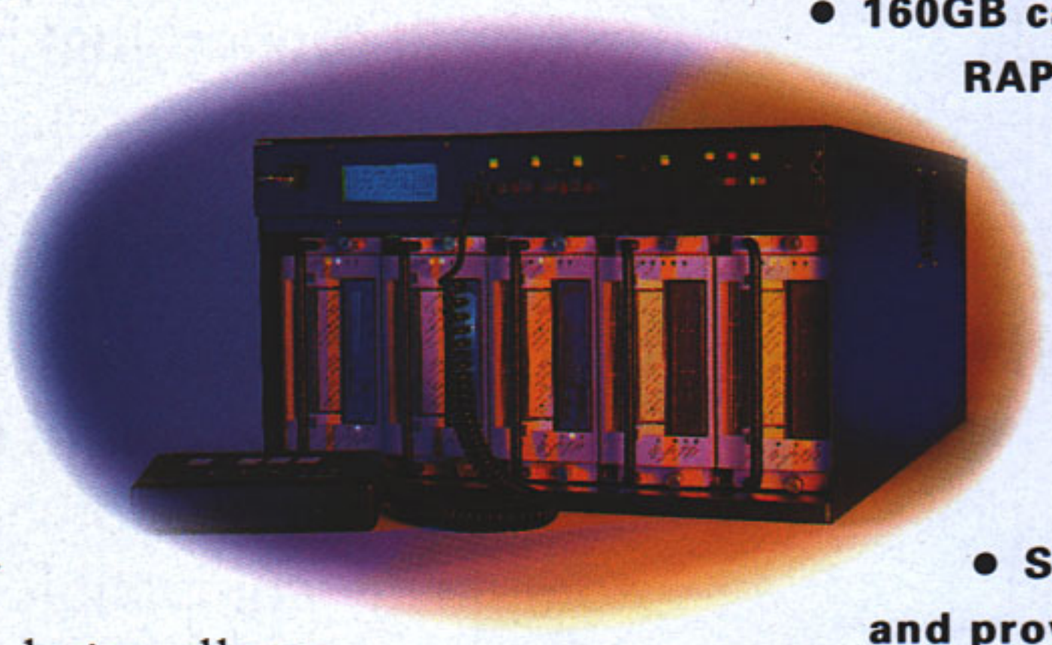

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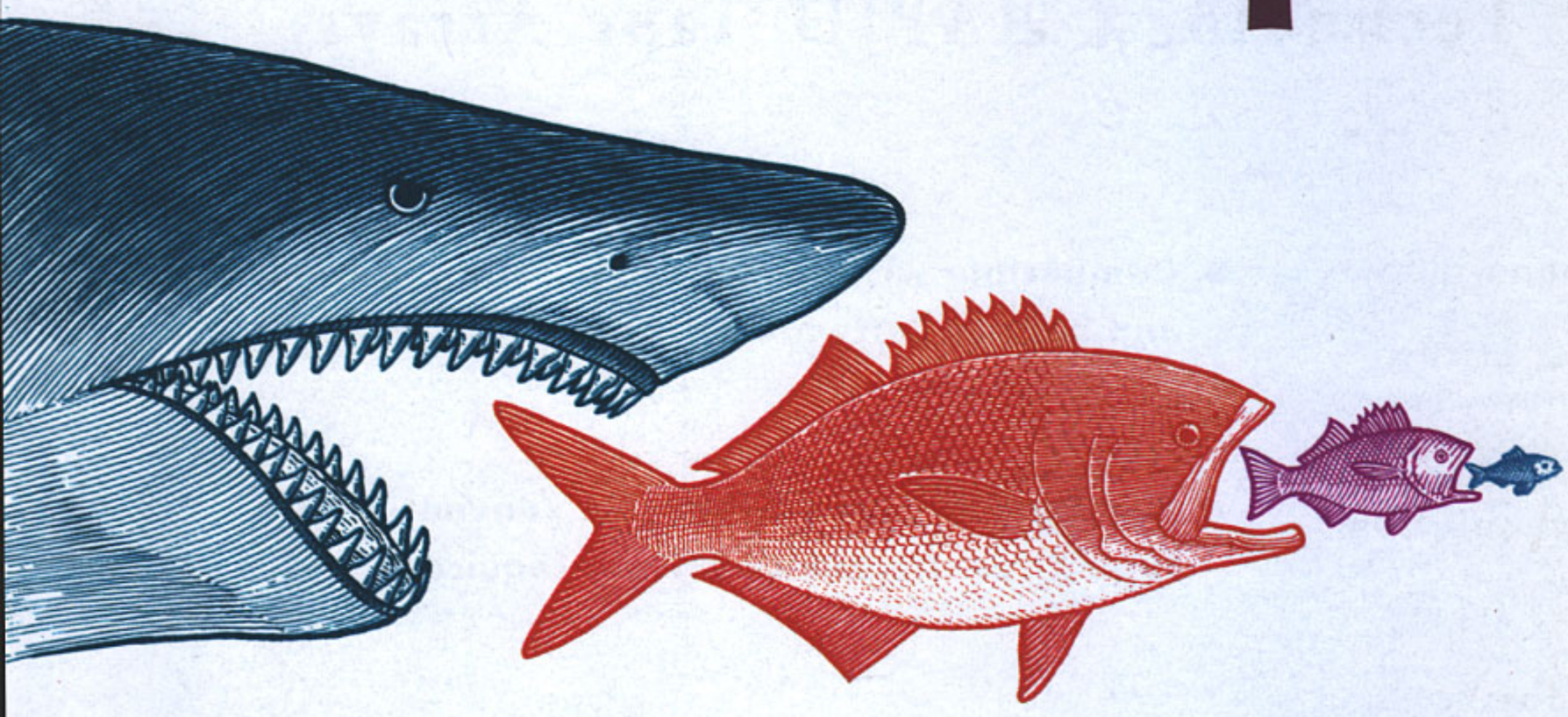

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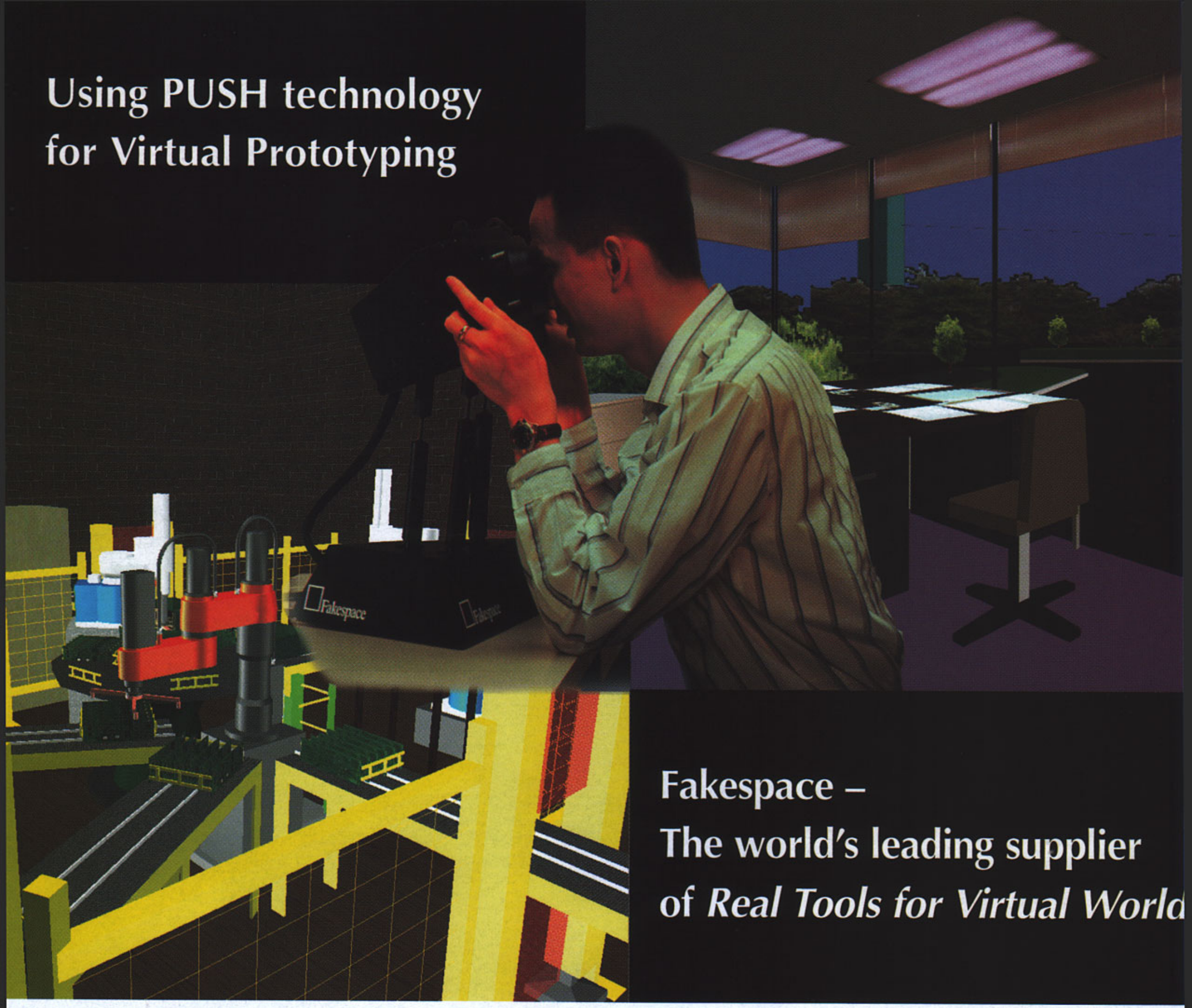

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Do It Digitally

When Ford Motor Company unveiled its new Taurus in October, the world got a glimpse of a radically new type of automobile. The difference wasn't in the number of wheels - there are still four - or the engine itself, which still runs on gasoline.

The 1996 Ford Taurus is revolutionary for the way it came to be. Working across time zones and geographies, Ford's design experts used the latest and most powerful digital engineering technologies to collaborate worldwide on the completely redesigned Taurus, one of the most popular cars in the world.

The message is that the art and science of engineering is changing. No longer do automakers need to carve huge, life-sized clay models of new cars to wheel into wind tunnels. Gone are the days when whole automobiles had to be sacrificed for crash tests. Today, it can all happen digitally, in real-time, and in 3D.

In a sense, that's what this issue of IRIS Universe is all about. Whether you're talking autos or trucks, buildings or tennis shoes, the idea is the same; the benefits, universal: Do it digitally and save time and money. Do it digitally and build a better, safer product.

Do it digitally and win.

Which brings us to another issue. Devoted to digital design, engineering and manufacturing, we're roaring out of the gate this time around with an impressive slate of articles focusing on people who are breaking new ground in this digital realm. Take, for instance, Lou and Robert Cobb's tale of the Canada Department of Public Works and its vision for a new building made to look, well, old. Or a look at high-styling new trucks from Grant Ellis. Or Mark Compton's slam-dunk piece on L.A. Gear and its success in staying a step ahead in the ever-changing athletic shoe market.

Or, of course, Grant Ellis' other very timely feature on Ford's Global Design Studio, one of the revolutionary digital cyberplaces inhabited by those who are deciding the shape of things to come.

—Carl Furry

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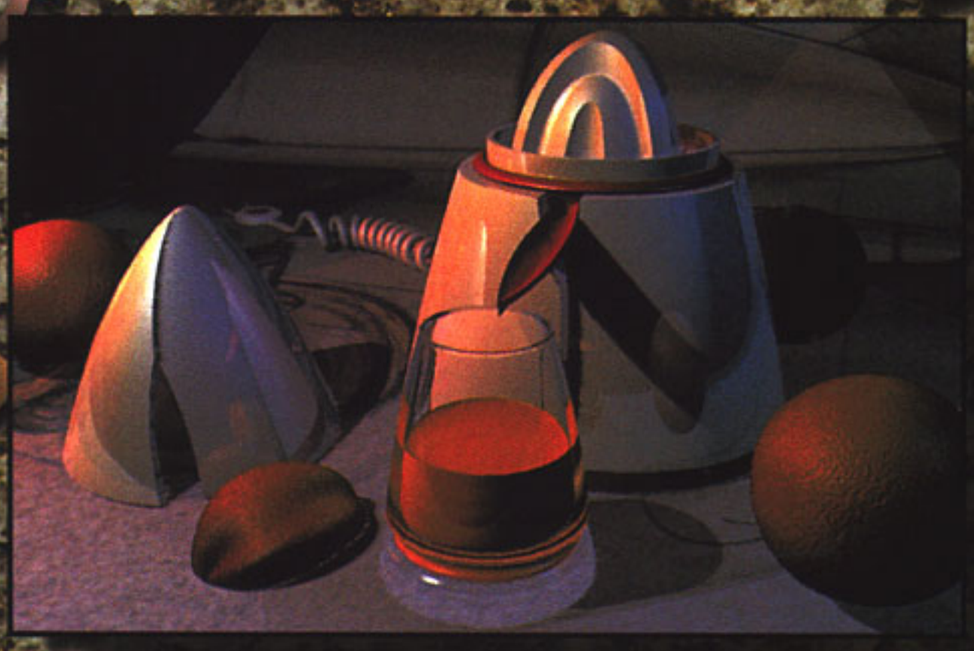

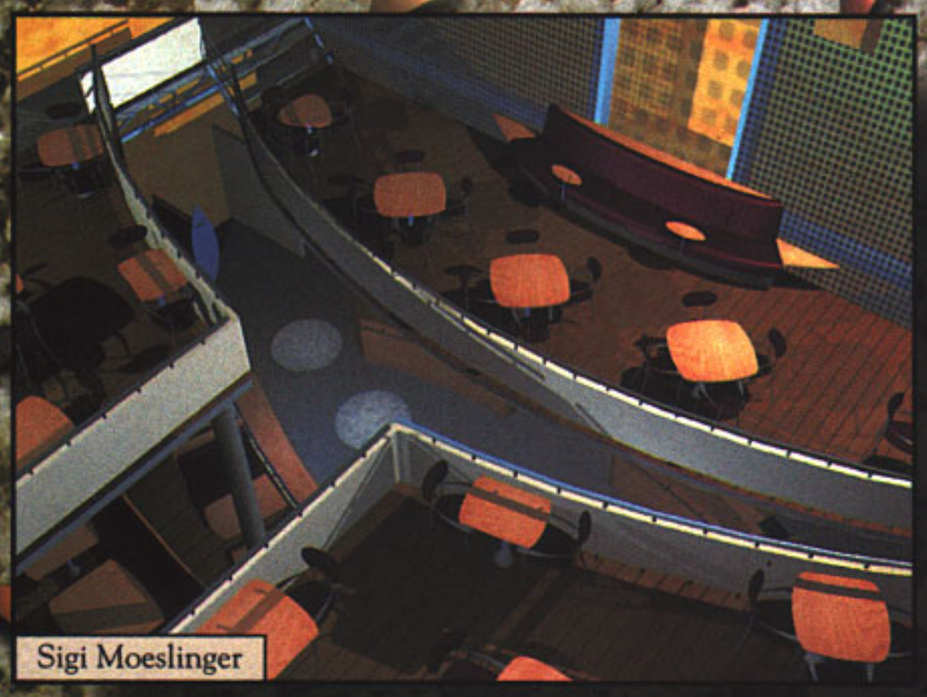

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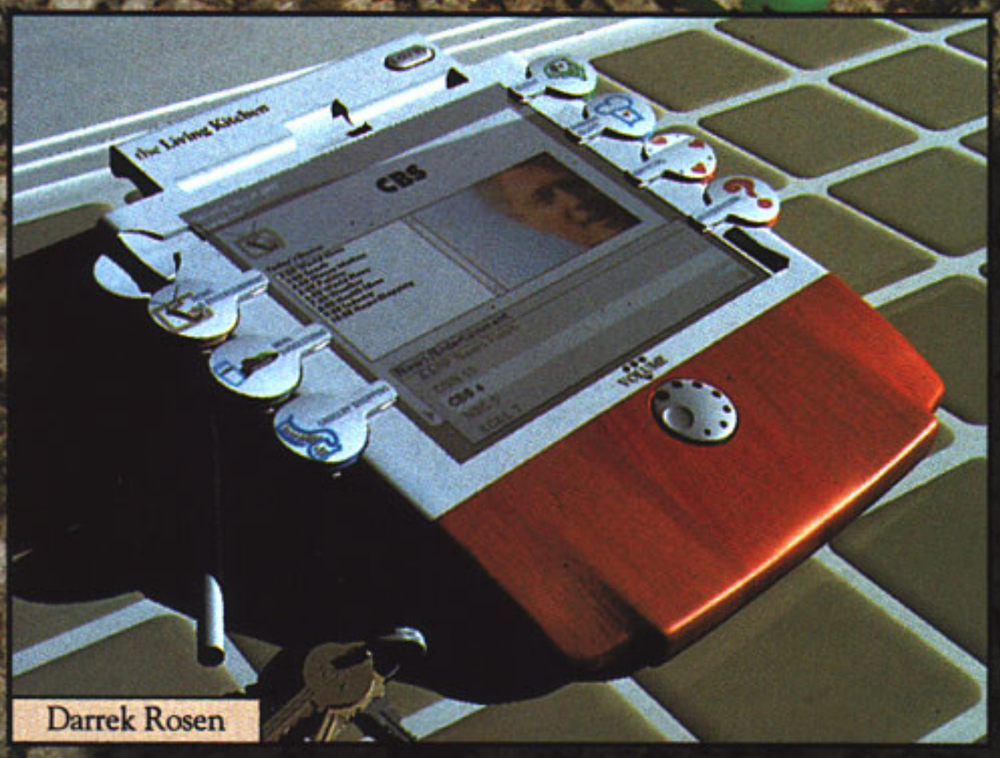

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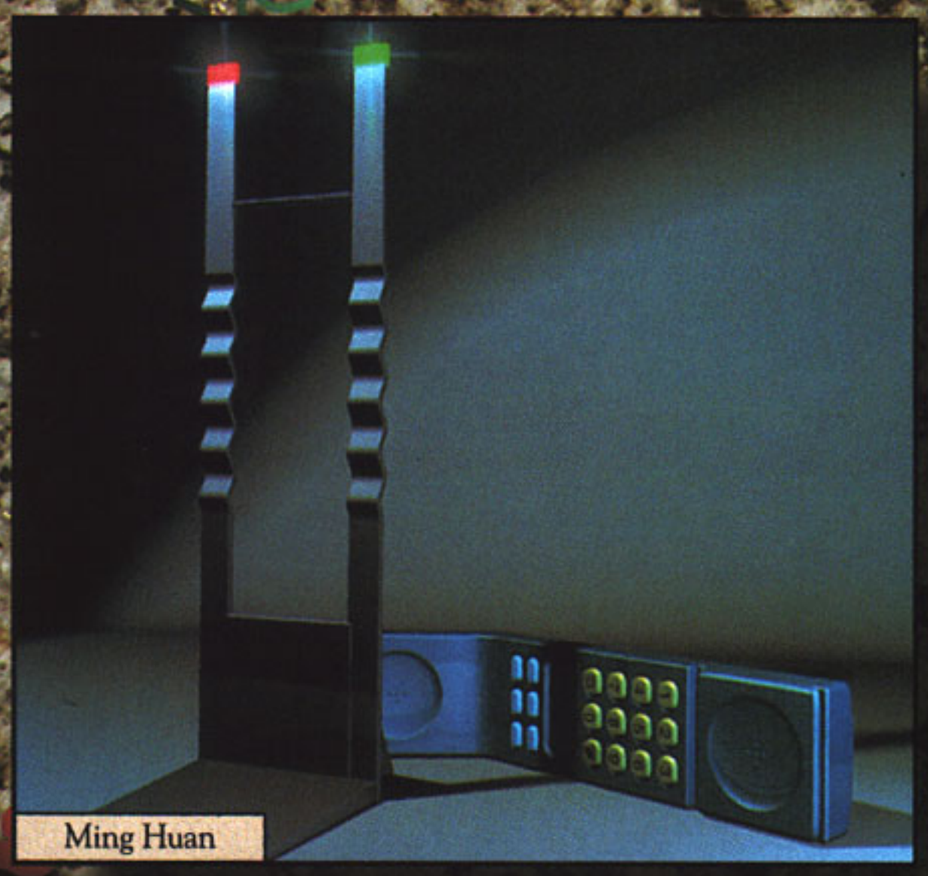
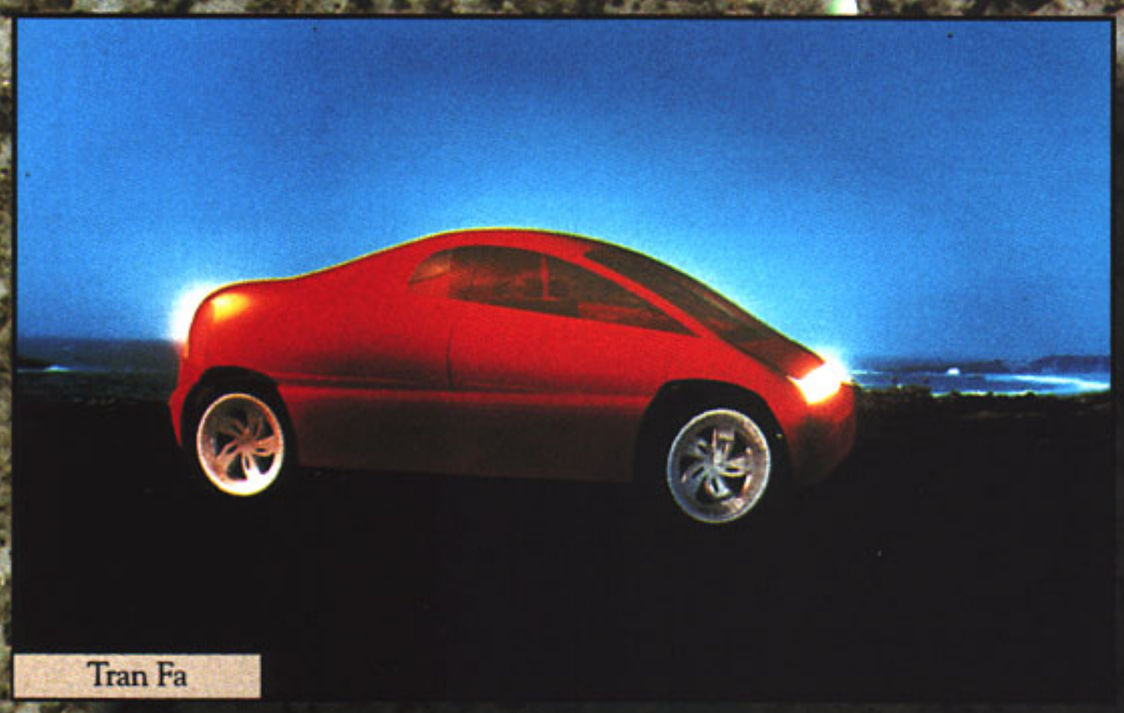


Ming Huan



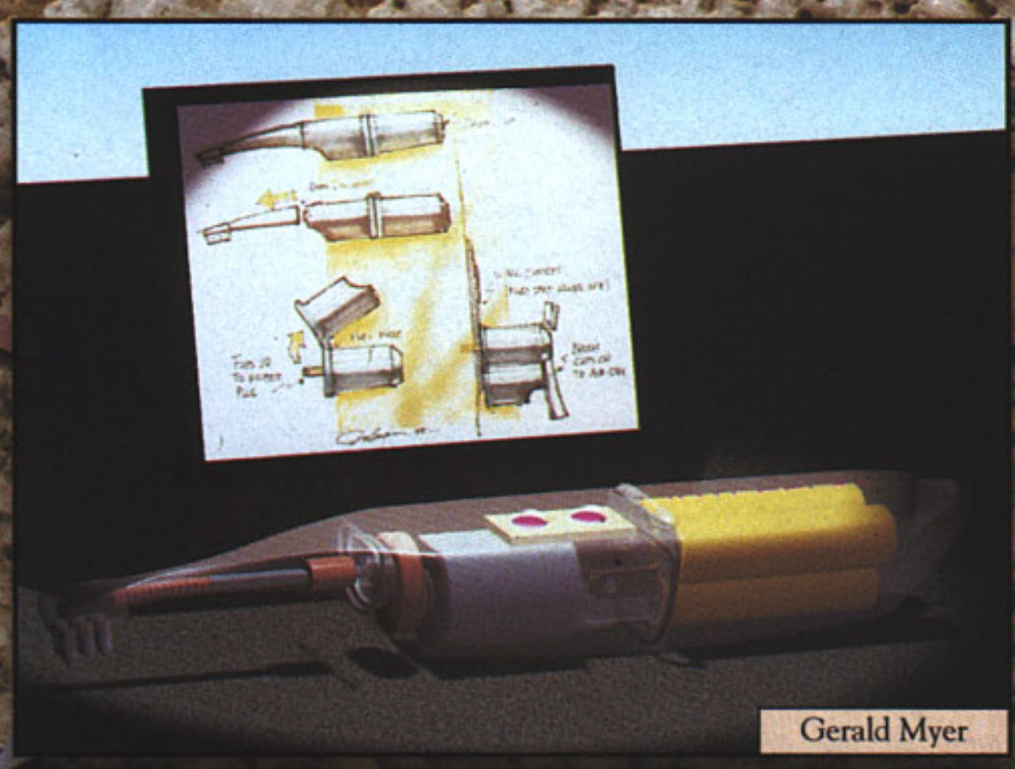
Tran Fa

Art Center College of Design, an international leader in art and design education since 1930, is an independent, nonprofit, four-year college specializing in the design arts.

Presented here is the work of some of Art Center's exceptionally talented students. These computer generated images represent several Art Center projects, including a conceptual "everything car" featuring an articulated roof which rolls back to reveal a pick-up truck bed, designs for futuristic counter-top appliances, and the results of a study for a new Bausch & Lomb dental hygiene system.

All images courtesy of Art Center College of Design © 1995

Ryan Ishihara



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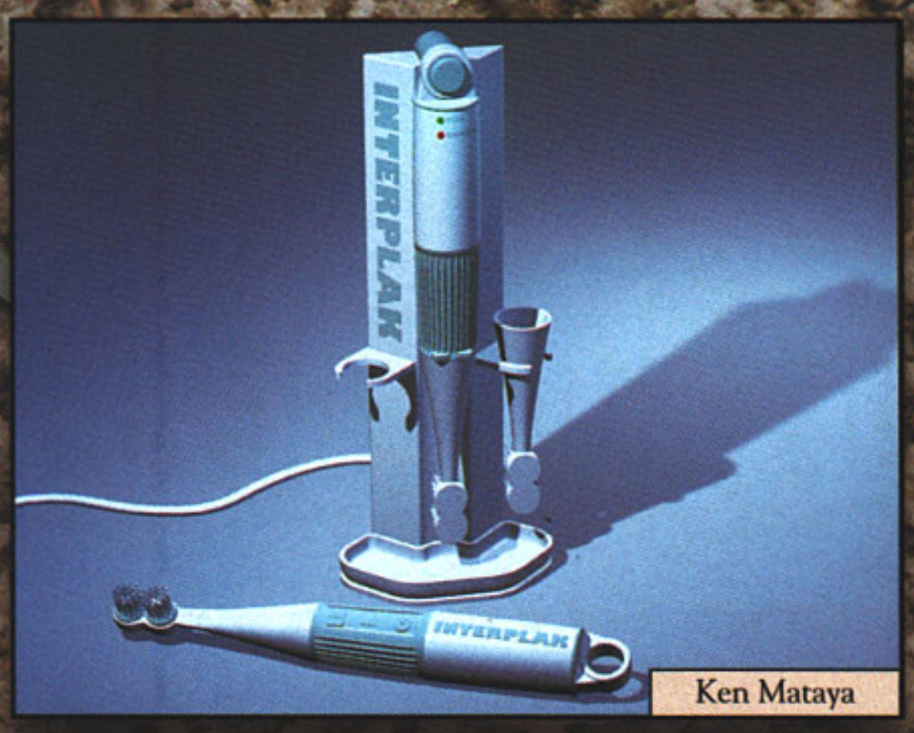

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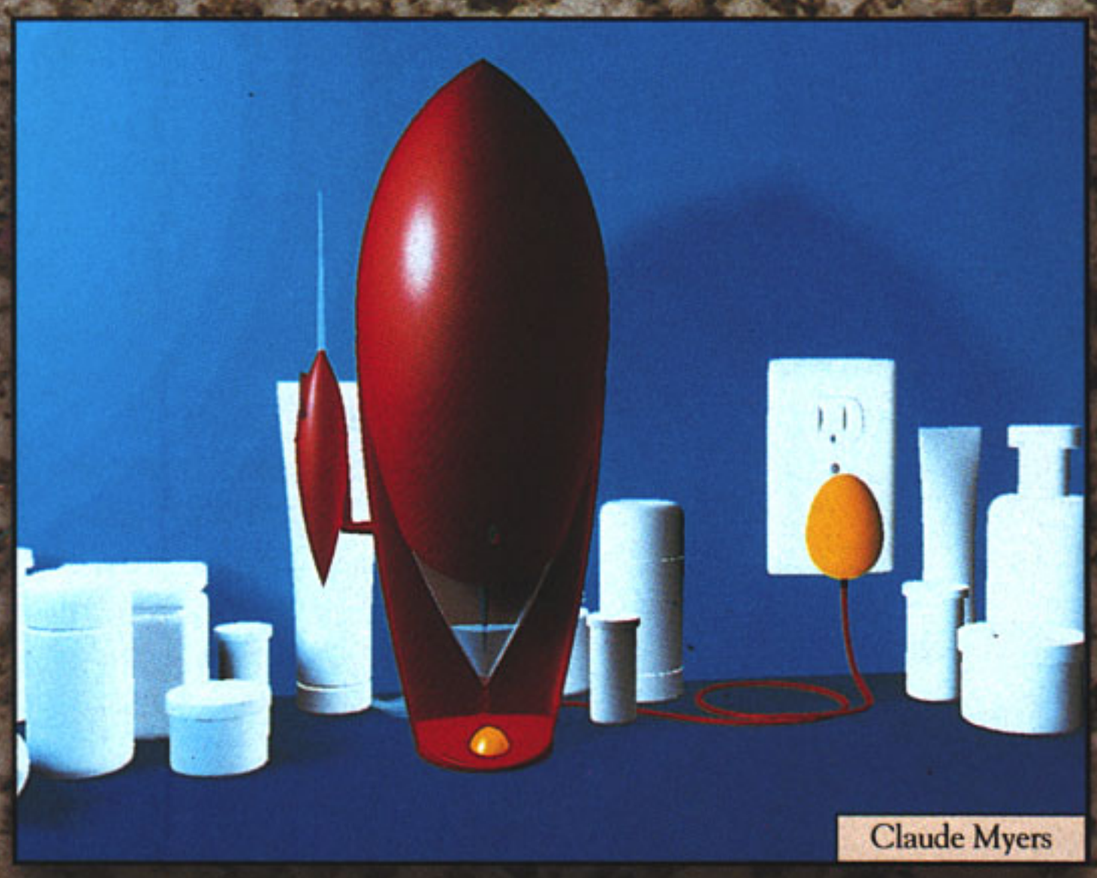

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At the center of Mega Drive's award-winning RAID disk arrays is an active backplane that provides millions of hours of reliable performance. Built on a hardware-based RAID architecture and **hot swappable drives, power supplies and fans,** Mega Drive RAID disk arrays run complex applications year after year without ever skipping a beat. To further increase the fault tolerance of the Mega Drive arrays, the MX/500 is available with redundant controllers, remote pager modules and hot spare options.

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Images courtesy of Freightliner Corpration

FREIGHTLINER

High-Styling the Big Rigs

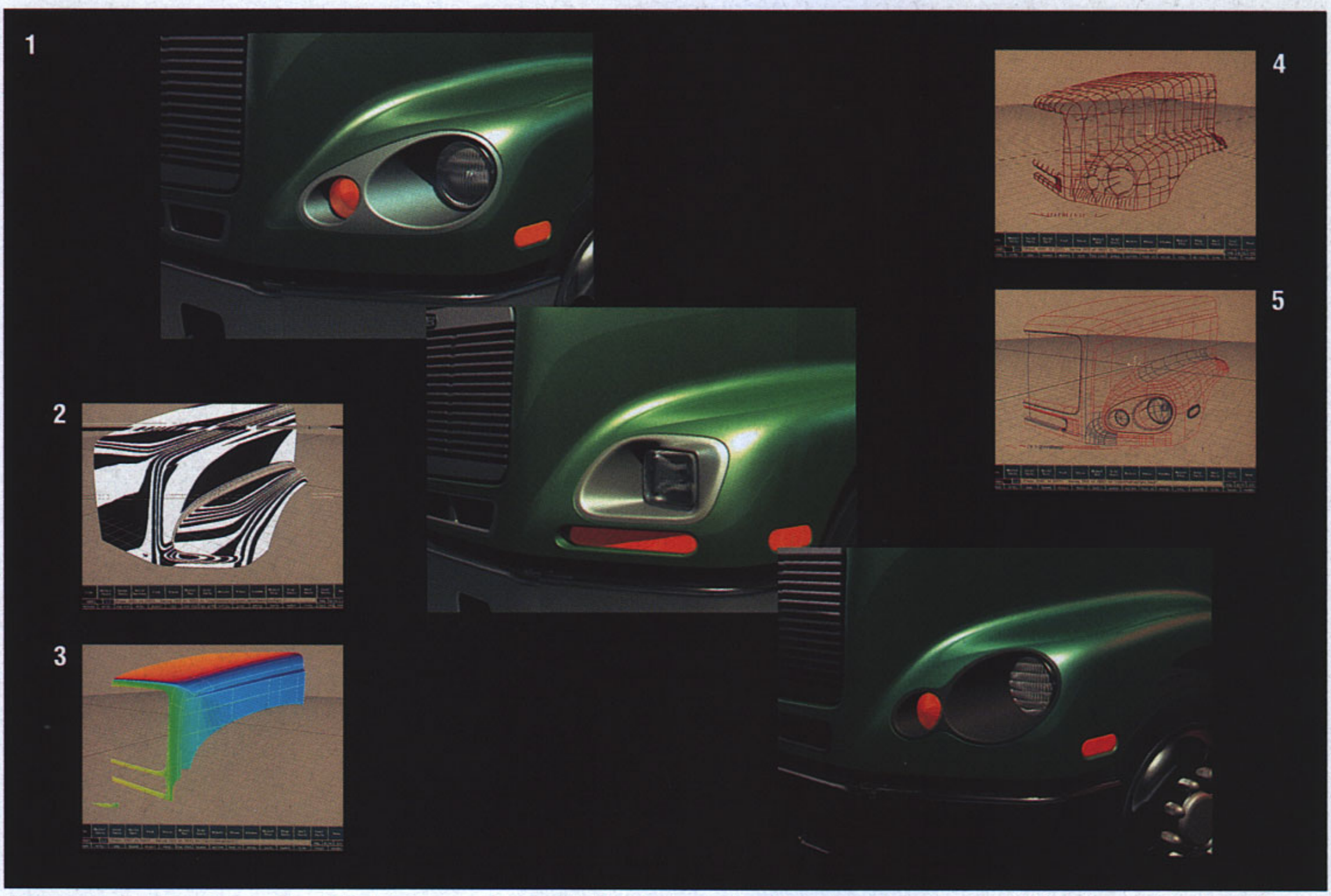
By Grant Ellis

The era of spartan highway transport is passing away before our eyes. True, we still see some hard-bitten truckers bouncing along interstate concrete in comfortless, bare-bones cabs. But those trucks are a dying breed. Pull out on the interstate today, and you're more likely to be passed by big rigs with sculpted lines, contemporary colors, and an air of comfort and power. This is not a superficial trend, like baggy pants on skateboarders. It reveals a major, ongoing change in the over-the-road trucking business in the United States.

Keeping 'em Happy: Fit, Finish, and Amenities

In the last few years, turnover has become an inescapable plague for the trucking industry. Fleet operators are finding it increasingly difficult to attract and keep capable, reliable drivers. Recruiting and training costs have escalated to painful levels. This circumstance has forced the fleets to take a different view of the big-rig tractors they buy and lease. The burning question has always been, "What's the life-cycle cost of operating this tractor?" To this they have added the question, "Is this a cab that will keep my drivers happy?" On the road and at the truck stops, fleet drivers see the handsome, sometimes glitzy rigs of the owner/operators, and say, Why not me? When applying for a fleet job, the comfort and style of the rigs they're asked to drive will make a difference—especially if their schedules call for long periods away from home.

This shift in emphasis is of intense interest to Freightliner Corporation, a Portland, Oregon subsidiary of Daimler Benz that presently holds 25 percent of the Class 8 market (trucks of 33,000 pounds and over). In 1994, major freight haulers and leasing companies spent nearly $4 bil-



1.Three distinct iterations of headlight design rendered with Alias Auto Studio. **2.**A simulation of reflected light is used to check the surface of the fender. **3.** A gaussian block visual representation of a second derivative of a surface, showing the rate of change of curvature of a FL112 hood. **4.** Alternate wireframe version of headlight treatment. **5.** Final wireframe version of FL112 headlight and fender.

lion acquiring Freightliner tractors and trucks, and operator comfort figured significantly on their wish lists. Consider America's most popular big rig: the Freightliner FLD 120 70-inch raised roof sleepercab. There's room to stand up in the sleeper, and screened windows and a skylight for light and air. There are amenities like a clothes closet, and constant temperature control for those hot days and chilly nights. Options include a refrigerator, a swivel passenger seat, and a choice of interior styling treatments.

"The number of amenities and the level of fit and finish that are expected in a truck today are much higher than they were just five years ago," says Freightliner's Luis Novoa, who is chief engineer, body engineering. "The elaborate trucks we used to design and build for owner/operators and small fleets are now common even in big fleets. "I think you could say that the styling is changing from the purely visual to include sound and feel as well. That makes this work more and more important."

Silicon Graphics Systems: Beating a One-Year Deadline

This styling revolution has escalated competition between truckmakers and accelerated new-model design cycles. Freightliner, which faces powerful competition from truckmakers like Mack and Ford, has retained a competitive advantage by keeping design cycles short and delivering new models in a timely way. The company recently met this challenge head-on with Silicon Graphics workstations. Freightliner was faced with a go/no-go decision: bring a new Class 8 truck to market within a one-year window of opportunity—or let it pass. Could it be engineered, styled, and tooled up in that time? Not if we have to work with the usual clay models, said Novoa. But he knew that if his department could eliminate all the clay models but one, and use Silicon Graphics workstations for the design iterations, they could make the deadline. He said yes. "Without the workstations, we wouldn't have attempted the project," says Novoa. "Our mainframe-based system has neither the speed nor the high-resolution graphics required for styling. However, we were confident that our Crimson™, Reality Engine™, and Indy™ R4400™ SC workstations would enable us to meet the tight deadline." And they did. The FL 112 heavy-duty big rig appeared on time, looking good—and with a substantially reduced price tag.

"We not only completed the project by deadline; we did it at considerable cost savings," says Novoa. "By replacing two, and possibly three, physical models with computer-generated 3D models, we shortened the design cycle and eliminated about $4 million in development costs." The styling department machined one full-sized clay model, using data from the Alias 3D computer model and Freightliner's NC programming system, where the tool

Above: Light reflections being simulated on the surfaces of a moving FL112.
Inset: Actual photographs of the FL112 in its final form. All photos © Dale Moreau of the Freightliner Corporation

paths were generated for production tooling. The stylists then refined the physical model manually. While product design was still under way, the tool shop machined the master model. This represents a leap forward in time-to market.

"Tool building doesn't usually begin until the design is almost finished," says Novoa. "But because we knew the computer models were highly accurate, the tool shop was able to accelerate its work. In fact, the computer models have helped cut rework and scrap costs on almost all projects by 50 to 60 percent."

Ergonomics: Not Making Them Too Comfortable

"It's very important, from our standpoint, that drivers be able to operate the truck without fatigue for as long as possible," says Novoa. "On the other hand, you also want to keep him alert. In many ways, that conflicts with the idea of comfort." Engineering ergonomics into the driver's environment therefore becomes a complex balance of comfort, safety, and marketability. Truck manufacturers can make their cabs more salable and appealing by adding amenities and making them comfortable. Too much comfort, on the other hand, can make put a tired driver in jeopardy. All these things come into play when Freightliner designers use Silicon Graphics workstations to design dashboard layouts and cab interiors, which are increasingly important from the marketing standpoint. The texture-mapping power of the RealityEngine graphics system is used to simulate seat, door, console, and dashboard finishes in a variety of interior designs and colors.

When Aesthetics And Aerodynamics Collide

Novoa's design team downloaded a complete mechanical concept of the FL 112 from the mainframe to their Silicon Graphics workstations. The concept existed in the form of CATIA models, each representing an FL 112 subsystem. The subsystems were assembled into a single 3.5MB structural/mechanical model, and the styling design team went to work. "Sometimes," says Novoa. "we define a structural envelope around the mechanical structure. Then we define the space within which the style surface can reside. Within that envelope the styling designers have complete freedom to work with shapes, textures, colors, and materials."

Using Alias™ software, the design team created a distinctive look: smaller grille, with a horizontal slot below; wraparound fenders; round, sunken parking lights and headlights. They created a basic model, a model with an extended cab containing a berth, and a model with a full-sized sleeper box extension. They surfaced and shaded their models into photo-realistic 3D images that they could present to management as style options.

"The computer-generated models were as comprehensive as clay models," says Novoa. "We could rotate the designs so that management could view them from all angles. Every detail, from the lines of the hood to the grilles, was crystal clear."

Once the concept was established, mechanical and styling design were fast-tracked simultaneously. Using the Silicon

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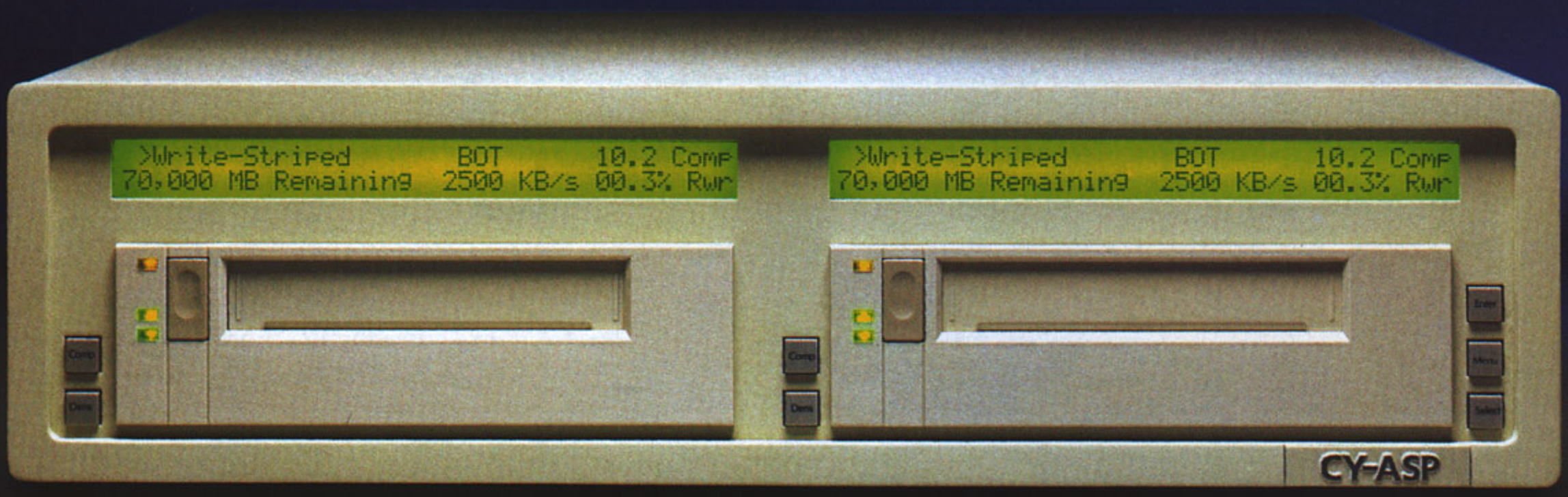

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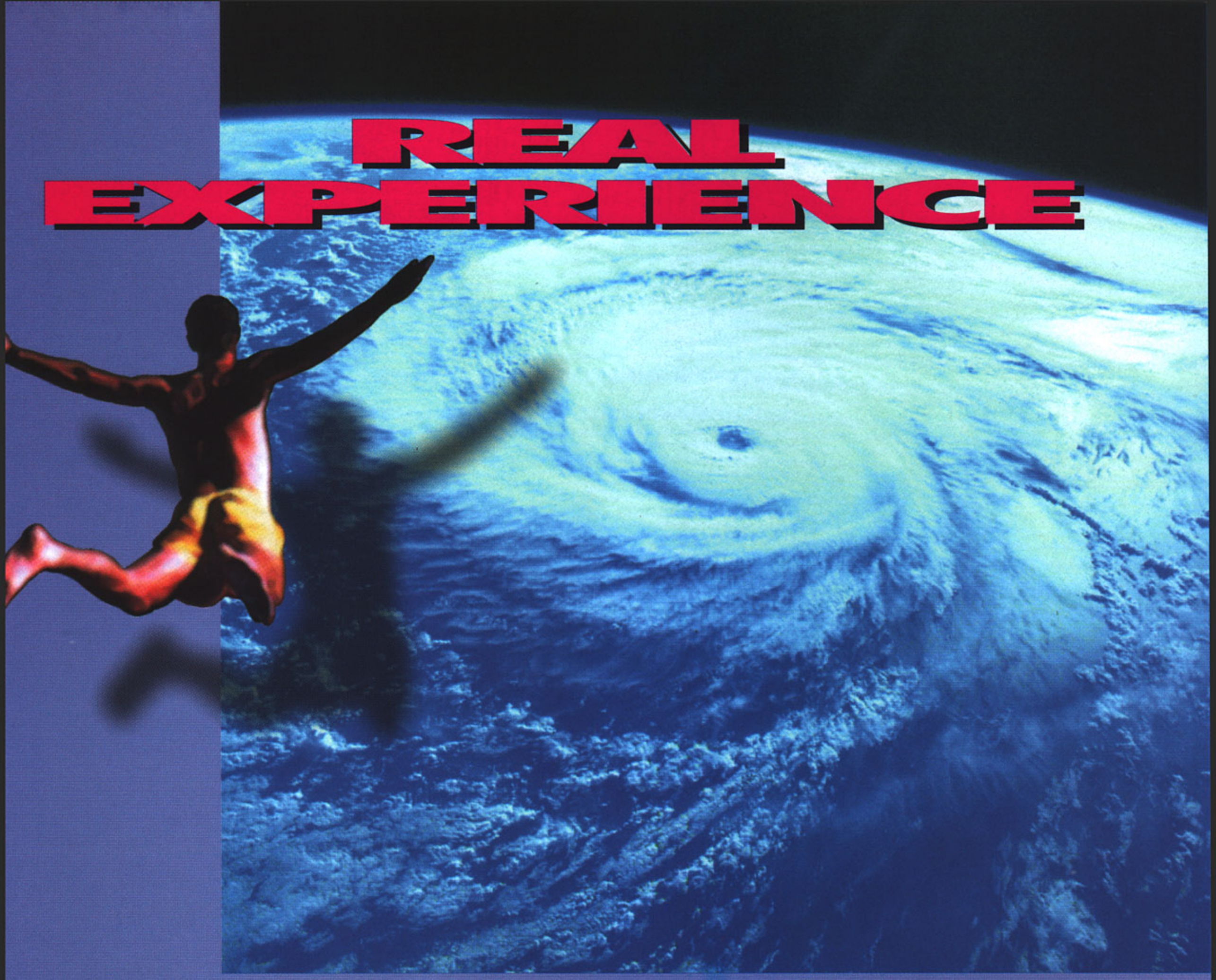
Graphics workstations, the team was able to reduce the amount of surface-styling time significantly. Where esthetics and aerodynamics collide, as they did at the FL 112's headlights, Silicon Graphics performance and Alias software contributed greatly to the completion of the design.

"The shape of the body surface around the lamps is critical," says Novoa. "If you have turbulent airflow around the headlamp cavity, you'll accumulate ice or mud in winter, and in extended driving you'll lose illumination. And of course it's important not to have any more drag than necessary." The team generated at least 20 variations on the basic design before the surface was esthetically and aerodynamically acceptable.

"The Silicon Graphics workstations provided the high color and pixel resolution that enabled our engineers to spot surfacing problems quickly," says Novoa. "Without Indy, the headlight problem would have taken twice as long to resolve. "It's very important to us to know how to display a realistic picture of a part on the screen and examine it as if it was a real part. That's why graphics performance is so important to us.

"The real value of this technology is that in any given period of time you can try many more things. And arrive at a much better design. Because Silicon Graphics workstations render graphics so rapidly, we can create numerous designs and select the ones that work best, while the quality of the graphics ensures us a much higher level of design accuracy. And that contributes to keeping Freightliner trucks on the highways." ★

Grant Ellis (gellis@redshift.com) is a freelance writer who works from his Monterey Peninsula home.



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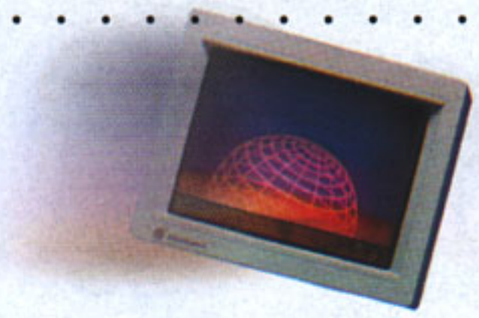

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Good Moves

In the high-tech game of athletic fashion footwear, combining technology and vision constitutes a dream team all its own.

By Mark Compton

For LA Gear, the best defense has always been a hyper offense—sort of a fast-breaking approach set on fast-forward. In the rough-and-tumble game of marketing athletic footwear, there's just no other way to score.

The pace of the market is set according to the rhythms of the inner city, where virtually every new streetware design must face its first and most crucial test. In general, the rule is this: if a shoe can't cut it with the homeboys, you may as well bury it immediately. And even when you do manage to score big, don't plan on staying hot for more than 30 to 60 days. Altogether, an exceedingly popular athletic shoe might have a total shelf-life of six months. Then it's time to make way for newer, trendier designs.

To prepare for this rather meteoric process, LA Gear currently spends between 12 and 14 months developing each product. With a major push, that can be cut to maybe eight months. But, like each of its competitors, LA Gear wants to streamline the process still more.

Too Good to Ignore

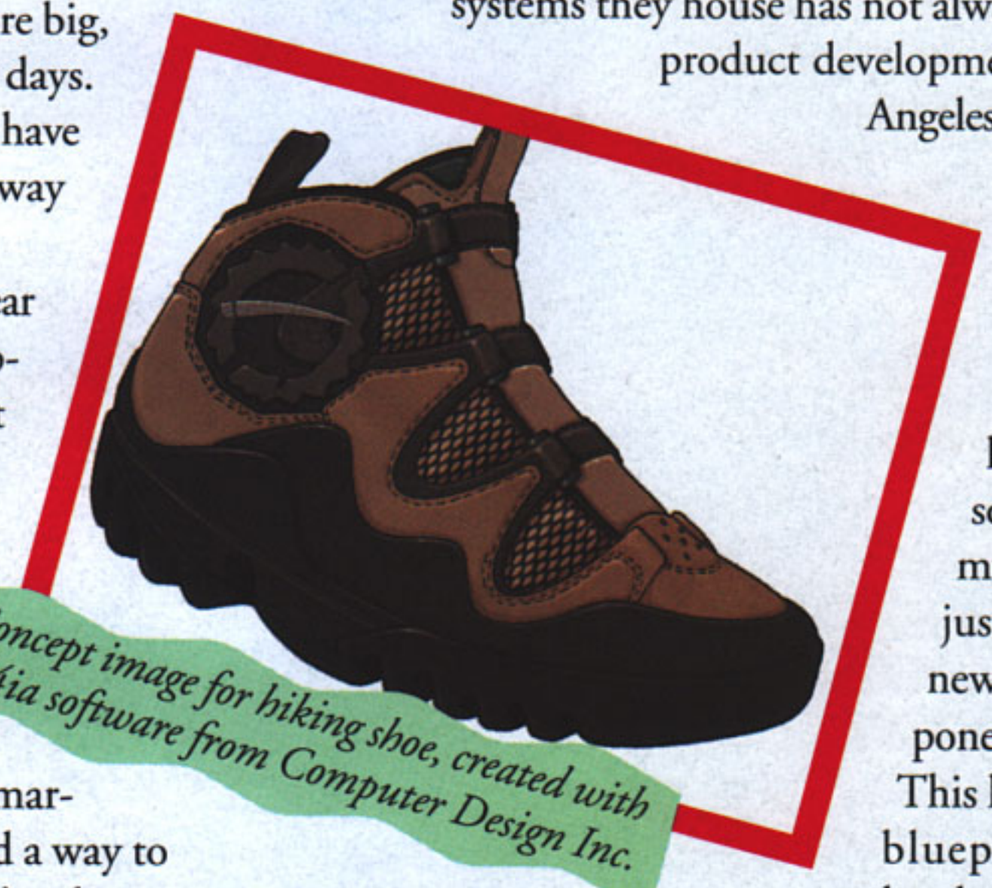
Besides the obvious potential for saving time and money, a design's chance for success in the market can only be enhanced if the manufacturer can find a way to move it to market faster. "After all, as a designer, you're always looking for cultural nuances you can play off in the design of a shoe," explains LA Gear's director of men's design, Erik Purdom. "But if it takes too long to get your product together, whatever opportunity you once saw may already be gone."

So, to investigate the possibilities for speeding up the process, LA Gear asked Price Waterhouse in early 1993 to explore emerging technologies and make some recommendations. After several months of exploration and testing, Price Waterhouse returned with its verdict: the advantages inherent in using 3D CAD systems with database support and advanced visualization techniques to better integrate product design, manufacturing, and sales were simply too good to ignore. A good first step toward implementing these capabilities, the report suggested, would be to install powerful graphics workstations throughout the product design group.

"The only software suitable for meeting our design challenges operates on UNIX platforms," recalls Raj Mistry, LA Gear's CAD/CAM operations manager. "The Price Waterhouse people were also fairly emphatic that high-end graphics were what were called for. So once they found that most of the really qualified design packages ran on Silicon Graphics systems, that pretty much ended the search. I don't think there really was much discussion of using anything else."

For years, several of LA Gear's best-selling lines have been making a design statement that speaks about as loud as any shoe possibly can. Light systems embedded into the soles illuminate whenever impact is made or whenever the foot's inertia is suddenly halted. The resulting flash of light—usually red—is almost impossible to miss. The impact on the market has been enormous.

But designing and manufacturing the soles and the subsystems they house has not always been easy. With product development centered in Los Angeles and manufacturing facilities located in Hong Kong, China, Taiwan, and South Korea, LA Gear historically has had to meet some daunting communication challenges just to prototype its newest sole and component system concepts. This has meant shipping blueprints and pencil sketches to the Far East, where manufacturing managers have tried to interpret them as best they could. The resulting prototypes have then been shipped back to the US for testing. At times, the prototypes were exactly what the designers intended. Often, though, they were not, requiring the whole process to begin anew.



Concept image for hiking shoe, created with U4ia software from Computer Design Inc.

Now, with the help of Pro/ENGINEER software from Parametric Technology Corporation, running on Indigo^2 workstations, designers can instead "generate precise control drawings based on real geometries," says Purdom. "With these, our mold engineers in the Far East have a chance to really investigate the structure of a new design before any serious commitments of time or money are made to tooling or prototyping. That

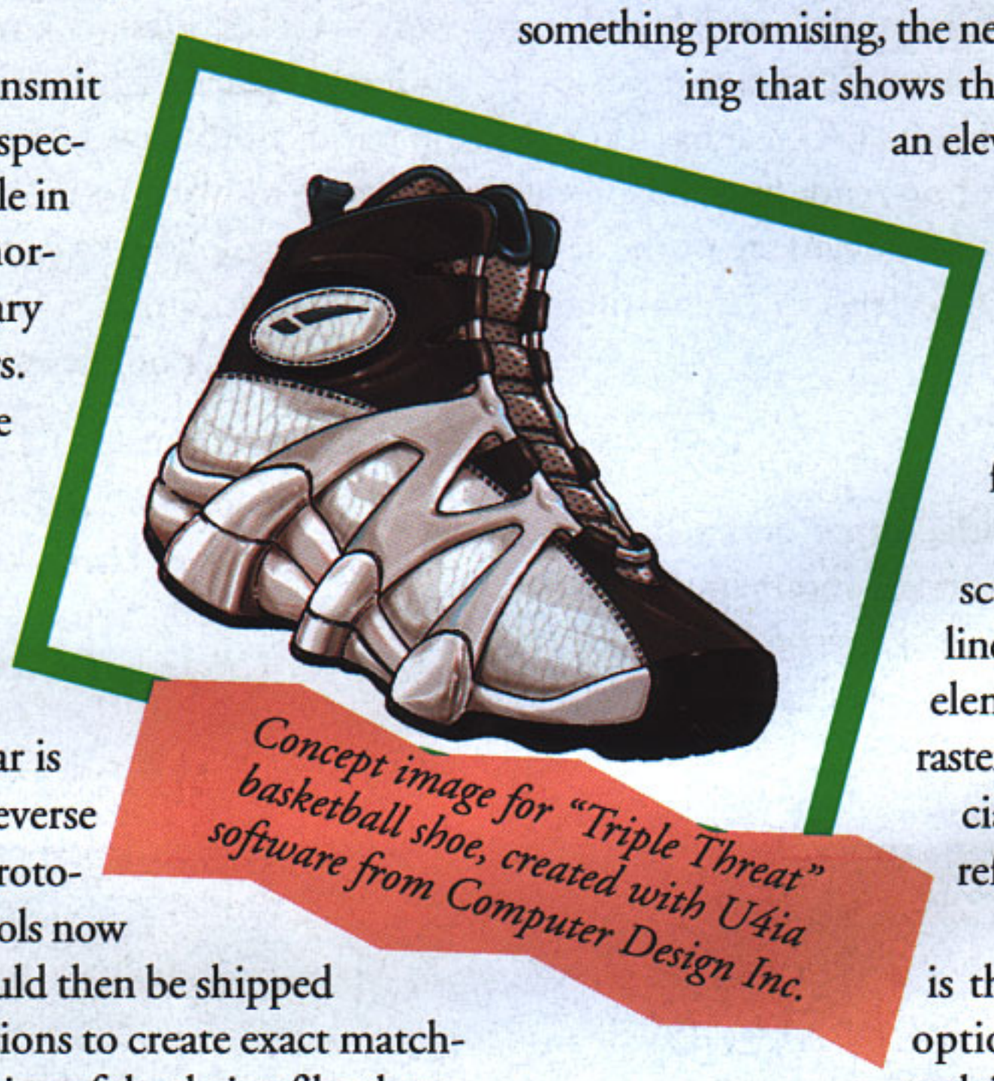
makes a huge difference, mostly because we're now able to provide such accurate directions—and that really reduces the potential for confusion or misunderstanding."

Through the sharing of the actual underlying geometries, all ambiguity is alleviated. And Purdom insists that the exchange of 3D CAD databases is sure to become a reality once dedicated leased lines for data and communications are established between LA Gear headquarters and each of its Asian sourcing agents.

"Right now, all we have is a local network supported by dial-up lines for use with cc mail," explains Mistry. "But the bandwidth that this offers just isn't wide enough to handle our CAD files, which do tend to get rather large. Once those leased lines are in, though, we can begin to send the files themselves, and then manufacturing can work directly from those."

By using the leased lines to transmit accurate visuals and precise product specifications to manufacturing, the people in production will find that they can thoroughly review and make any necessary adjustments to a design within hours. The modified design will then be shipped easily back to headquarters for final approval. It will become possible to compress into a few hours or days a process that historically has required weeks or months.

Another possibility that LA Gear is now actively exploring is using reverse engineering technology to develop prototype models by using various CAD tools now in place. The resulting prototypes could then be shipped to manufacturing sites, with instructions to create exact matches in production. As with the transmission of the design files themselves, this will help to make communications with manufacturing perfectly clear—which, as well as alleviating unnecessary delays, offers the best hope for maintaining product consistency across multiple manufacturing facilities.



Concept image for "Triple Threat" basketball shoe, created with U4ia software from Computer Design Inc.

Half the Battle

Producing soles and their associated components, of course, is only half the battle. Accordingly, the streamlining plan laid out for LA Gear by Price Waterhouse also calls for the use of visualization techniques to simplify and speed the design and manufacturing of uppers. Prior to acquiring several Silicon Graphics systems for the product design group, the conceptualization and refining of new designs was handled almost strictly as a pencil-and-paper exercise.

Freehand sketching remains the preferred process for initial product ideation, Purdom explains. "But now it's a given that once you get your initial concept banged out, you'd be crazy not to do the rest of your work on line. It's just so much faster to go in and change things that way. And then you can also print out a fresh, clean iteration whenever you want to without having to take the time to first draw a new illustration."

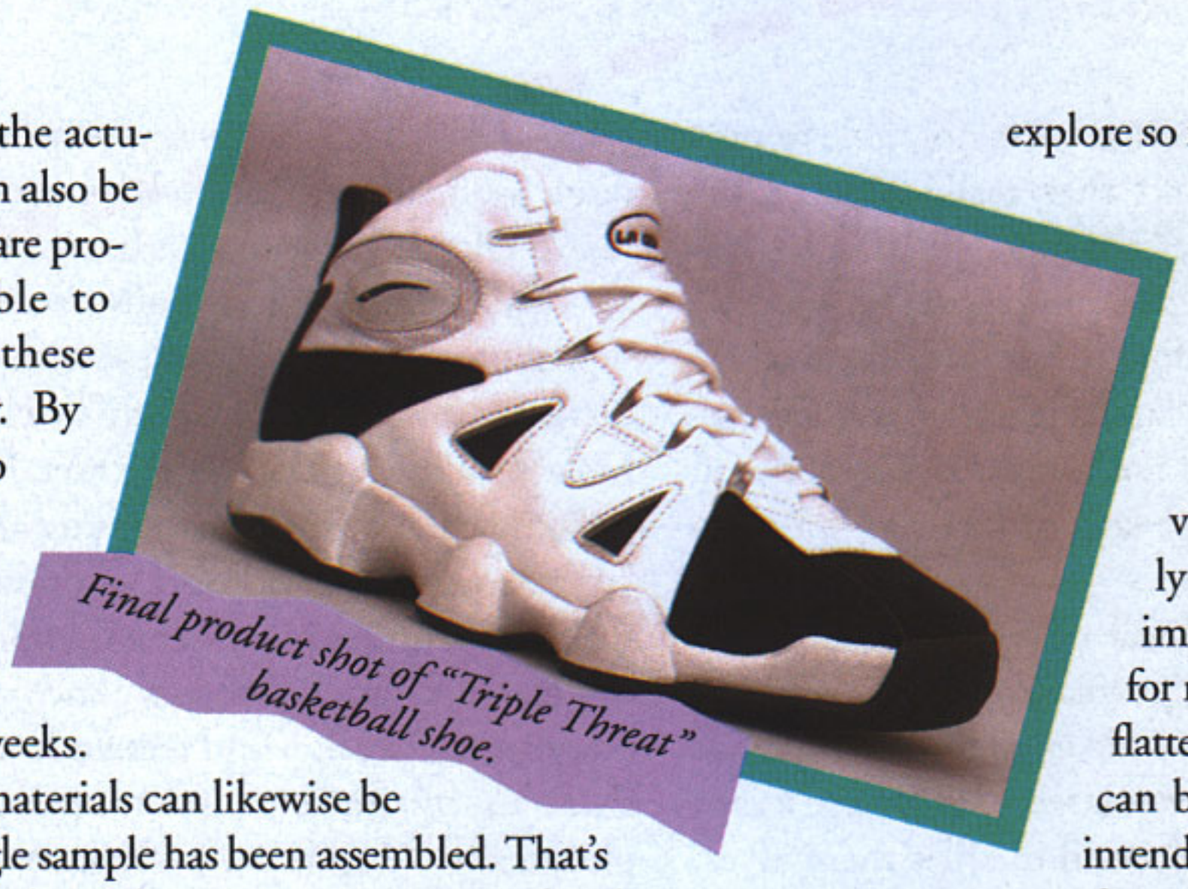
Previously, Mistry recalls, "you'd have a nice drawing of a new shoe concept —complete with all your proposed colors or textures—and then somebody would say, 'No. Change the toe. Make it a little higher. A little lower. A little rounder." And, before you knew it, you'd end up erasing and redrawing huge parts of your design. Or you'd have to draw something altogether different on another piece of paper, and then paste that onto your original illustration. But now, once you've saved your initial line art, you can tweak it and recolor it in a matter of minutes. And then, just by printing out a fresh copy, you can give other people a really clear idea of what you've got."

Typically, once the design team can agree that they're onto something promising, the next step is to produce a clean ink drawing that shows the shoe from either a lateral view or an elevated perspective. This in turn can be scanned into a package from Computer Design, Inc. called U4ia, which makes it possible to quickly apply a wide array of colors, textures, or patterns to the evolving form.

The textures themselves can be scanned in, using existing artwork, line-art, photos, or fabrics. To create new elements, U4ia also includes vector and raster-based drawing tools, along with special features that make it easy to edit, refine, and repeat motifs.

"The biggest thing U4ia does for us is that it lets us look at a lot of design options in a short amount of time," explains Purdom. "When we had to physically ink up each of the versions we wanted to look at, there were only so many possibilities we could consider. But now, because we can do a lot of color-ups in the space of just a few minutes, we can investigate many approaches we wouldn't have had the time to investigate before."

Similar advantages extend to LA Gear's executives, who must review as many as 300 different designs in preparation for each season, deciding which ideas are to be developed and which are to be dropped. Now, instead of taking weeks to prepare storyboards for these sessions, the design team needs only assemble "snapshots" of their evolving U4ia concepts. With the Showcase presentation capabilities that come bundled into every Silicon Graphics system, these images can then be quickly incorporated into an on-line slide show. This gives the executives a clearer picture of each of the concepts—and allows the designers to use the time that would have otherwise gone into producing storyboards to think up new possibilities.



Final product shot of "Triple Threat" basketball shoe.

As an added benefit, the actual U4ia files themselves can also be opened whenever changes are proposed, making it possible to implement and review these modifications on the fly. By eliminating the need to reconvene the executives at a later time, this alone can help to trim the time required to bring a product to market by several weeks.

Sales and marketing materials can likewise be produced before even a single sample has been assembled. That's because, with the ability to selectively map new textures to already photographed designs or to insert renderings of virtual products into pre-existing images, promotional materials can be developed while manufacturing is still ramping up. As LA Gear has learned, the texture-mapping and high-resolution rendering capabilities built into U4ia make it possible to take advantage of the same image files already created for design reviews to create suitable catalog entries and sales sheets.

Slam Dunk

"Just in terms of streamlining manufacturing and achieving a closer working relationship between design and manufacturing, we feel we've already gotten our money's worth out of the Silicon Graphics systems," Purdom concludes. "Besides being able to explore so many more design options, the really important thing is that we now have a way to express our design intent so clearly that everyone can immediately see what we're trying to do."

And, even so, much of the vision that Price Waterhouse initially laid out for LA Gear remains to be implemented. Powerful capabilities for modeling 3D upper designs and then flattening virtual fabrics into patterns that can be seamed together to produce the intended form promise to streamline manufacturing even more. The necessary software—CDI's Design Concept 3D modeler and a footwear industry-specific application USM called Crispin—are already on hand. Both have been tested and shown to be effective and plans are in place to integrate them. According to Mistry, LA Gear is pushing for the change to come soon.

When it does, LA Gear expects to shift into an even higher gear, putting hot products out on the street faster than ever before. ★

Mark Compton monitors trends in graphics and multimedia from a comfortable perch midway between the Silicon Valley and Oregon's emerging Silicon Forest. Before becoming a freelancer, he served as Editor-in-Chief of both IRIS Universe and UNIX Review.

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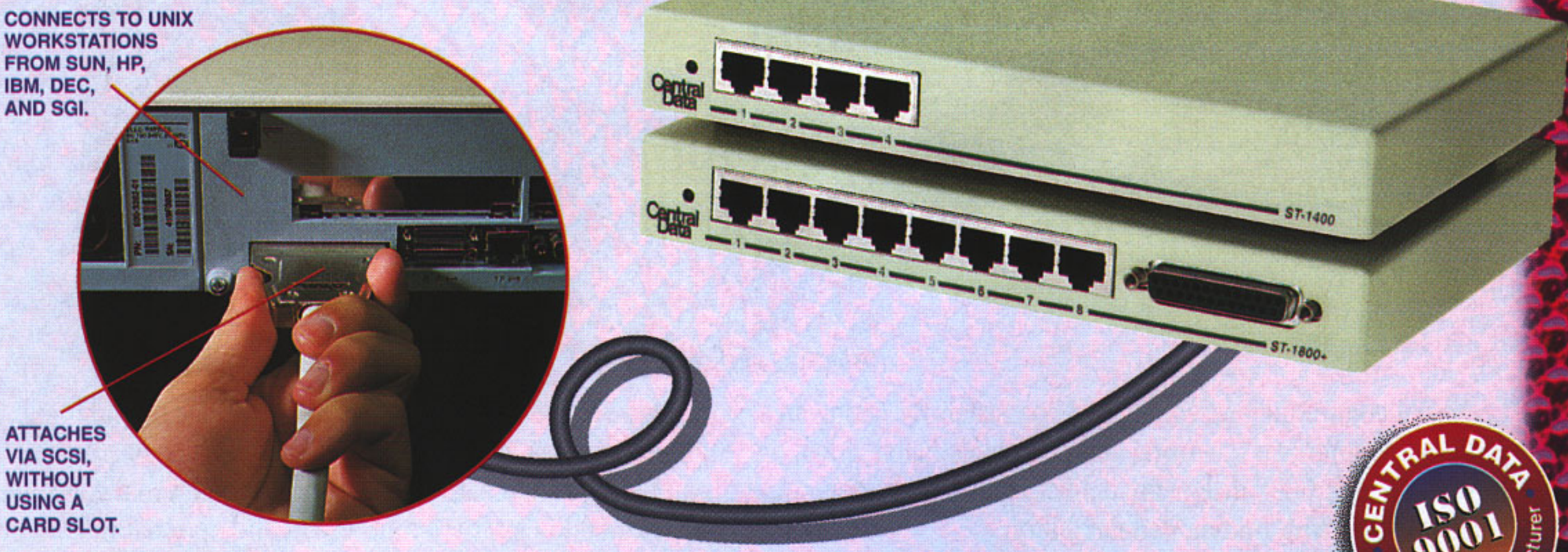

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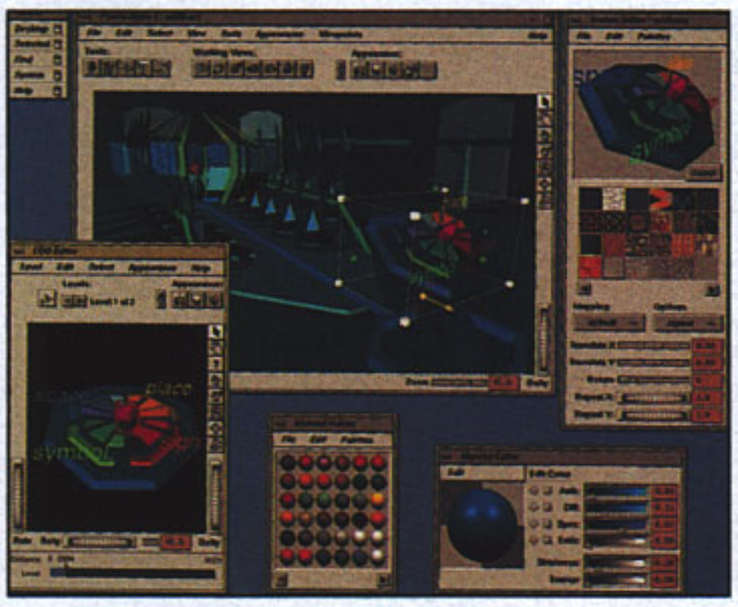
OPEN 2.1 INVENTOR

THE PERFORMANCE RELEASE

by Larry McDonough

You may have considered developing 3D applications with Open InventorTM but said to yourself, "No, that graphics toolkit it is too high-level, too object-oriented, too feature-rich. It can't be fast," You're in for a big surprise. With Open Inventor 2.1, which Silicon Graphics released this summer, developing high-performance 3D applications is easier than ever.



WebSpace Author by Silicon Graphics was developed in seven weeks using Open Inventor.

Open Inventor is an object-oriented 3D developer's toolkit that dramatically simplifies 3D graphics programming. You no longer have to be a graphics guru to develop high-performance, interactive 3D applications. With the ease and modularity of a toolkit, Open Inventor puts the functionality of OpenGL® at your fingertips, utilizing the best programming knowledge at Silicon Graphics.

Open Inventor contains a rich set of preprogrammed building blocks that define a full-featured, extensible framework upon which applications can be developed. The toolkit includes a wide variety of geometry, property, and group objects, as well as manipulators for user interaction, intuitive scene viewers, and editor components.

Applications developed with Open Inventor can be found in all major 3D markets, including industrial and computer-aided design, scientific and financial visualization, medicine, virtual reality, digital media production, animation, and entertainment. Interest in Open Inventor has grown significantly since the introduction of VRML (Virtual Reality Modeling Language), a subset of the industry-standard 3D file formatof Open Inventor. VRML is the platform-independent file format for 3D graphics on the Internet.

Developing Fast Applications

The primary mission of Open Inventor was to maximize frame rates. In most cases, application frame rates have increased 20 percent to 400 percent, with some gaining 1000 percent improvement after recompiling. Previously, maximum performance was achieved through the use of caching. Since caching is no longer necessary in all cases, Open Inventor 2.1 applications enable users to interactively manipulate more complex models while using less memory. Some applications, particularly those that extend the toolkit, will require code modifications.

The strength of the Open Inventor toolkit can be illustrated in the following real-life example: Silicon Graphics' WebSpace™ Author (an Open Inventor

IRIS Annotator by Silicon Graphics enables users to attach digital media annotations to 3D images.

application) went from an idea to beta-1 release in seven weeks. WebSpace Author is an advanced VRML authoring and modeling system complete with polygon reduction tools, numerous editing components (level of detail, material, texture, and more), precision "snapping" for aligning adjacent objects, object manipulators for scaling and rotating, tools for setting World Wide Web hyperlinks and inlines, and much more. The rapid completion of this advanced application could not have

Ez3d Modeler Pro 2.0 by Radiance Software is a powerful 3D modeling and raytracing application written entirely using Open Inventor

been achieved without the power and rich features of Open Inventor.

Great Open Inventor Applications

In addition to WebSpace Author, Silicon Graphics has developed many Open Inventor applications, and more are on the way. Among them are WebSpace Navigator (for browsing VRML worlds), IRIS Annotator™ (for annotating 3D models with digital media notes), IRIS Showcase™ (for presenting digital media slides), and InPerson™ (for collaborating on projects involving digital media).

Many commercial applications have also been built using Open Inventor. They include: Radiance Software's Ez3d Modeler, Visible Decisions' Discovery, Engineering Animation's VisModel, Alias/Wavefront's StudioPaint 3D, BE Software's BE Designer and BE Player, Digital Image Design's InScape, and The Numerical Algorithms Group's IRIS Explorer. In addition, the traffic on the usenet news group, comp.graphics.api.inventor, testifies to the fact that countless Open Inventor applications are being developed at companies for internal use as well as at universities for research and teaching purposes.

The Right 3D Toolkit

As product development cycles continue to shorten and users' expectations for 3D interactivity, speed, functionality, and interoperability continue to grow, the choice of an underly-ing development toolkit is a critical decision. To maintain competitiveness, your software development team must be able to prototype and deliver a high-quality product faster than the competition. Your toolkit must be a fast, easy to use, multiplatform, rich with features and functionality, standardized, and delivered by a reputable developer. Using these criteria, your decision is simple: Open Inventor by Silicon Graphics.

For more information on Open Inventor 2.1, be sure to check out the Open Inventor Web site: http://www.sgi.com/Technology/Inventor/ or send email to lardog@sgi.com. ★

Larry McDonough (lardog@sgi.com) is Product Manager for Open Inventor at Silicon Graphics. He is a recent graduate of UCLA's MBA program and has 10 years experience for various segments of the computer graphics industry.

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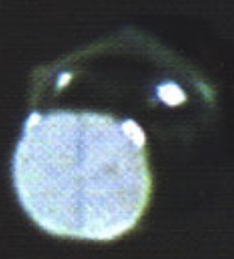

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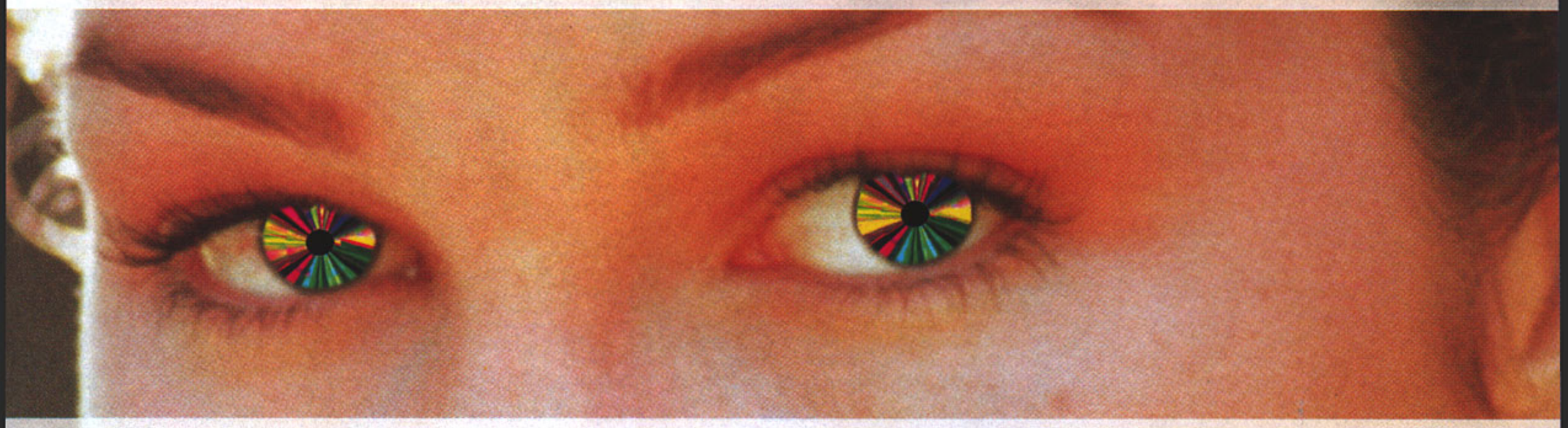

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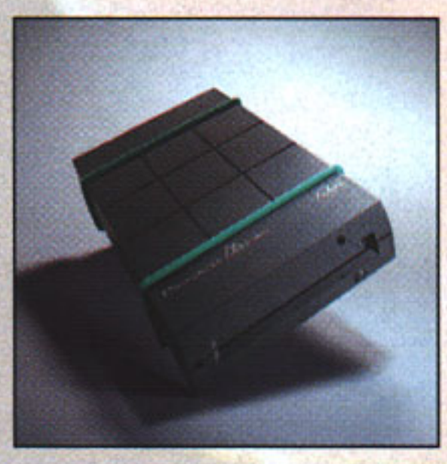

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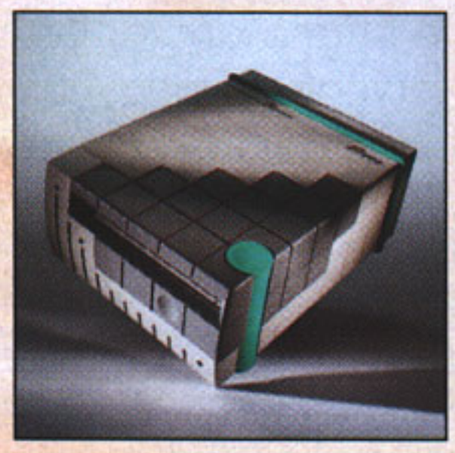

The Sierra 1.3 GB is the industry's fastest optical drive. It can be used as both a hard disk replacement and an on-line archiving system. Each 5.25" cartridge holds 1.3 Gigabytes of data, and boasts a 30-year shelf life. It is ideal for data-intensive applications such as graphics, CAD/CAM, multimedia or data archiving. ***$2,495***

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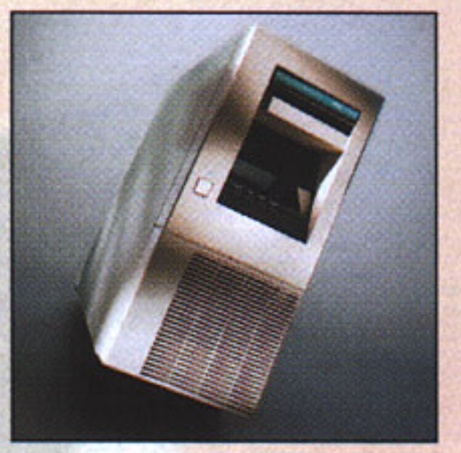

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Ford's Global Studio Shrinks the World—and Changes the Way It Works

By Grant Ellis

Images courtesy of Ford Motor Company, © 1995

The problem is, your shock tower as it stands goes right through my fender. And if I raise the fender, it's going to look super ugly."

"Well, how far above the fender does it go?"

"Here. That's it in blue. I'll circle it for you."

"Oh, yeah. About half an inch too tall. Hmmm."

"You're smiling. Does that mean you can fix it?"

"Sure. Watch this."

This conversation, relaxed and intimate as it sounds, is taking place across nine time zones. Two Ford designers, one working on body design in California, one designing suspensions in Germany, are chatting face to face, their eyes on each other and on the same drawing. The miles and kilometers that separate them, and the chilly North Atlantic, do not exist. In the words of Alex Trotman—the Ford CEO who is tearing down the barriers between Ford operations worldwide—they are co-located. What they're doing will inevitably cut Ford's costs, produce better cars, and get cars to market faster. But it is also doing something much more profound. It is changing the way people work.

"This is a cultural change as much as a technological change," says Ford Chief Designer Giuseppe Delena. Silicon Graphics workstations and dazzling software like InPerson, IRIS Annotator, Showcase, and Inventor provide the technological underpinnings for what Ford calls its Global Studio. But the technology is so effective that it seems to step out of the way and let people communicate.

"The people who are using this technology adapted to it easily," says Delena. "I mean, it's not a hard thing to adapt to. If you can make a phone call, it's certainly not too far beyond that. It's like giving candy to a kid." Delena's colleagues were eager to work with the technology, and that is significant.

"These people are not techies," says Silicon Graphics Vice President Joe DiNucci. "They're not even engineers. They're designers, stylists, and artists. The command we got a few years ago from Jack Telnack, Ford's Vice President of Worldwide Design, was 'Link these people. Make their geographic separation irrelevant. Make it so they're virtually co-located.'"

The Global Studio has done that. Transoceanic conversations, complete with interactive graphics and live video, are now routine between Ford design centers in Michigan, California, Japan, England, Germany, and Australia. The greatest benefit to Ford, according to Delena, is pure real-time collaboration.

"The ability to work in a collaborative mode internationally is an advantage in itself, because that translates into the ability to operate as a global company—a leaner, faster, company—and produce world cars of higher quality. One fallout of that, we hope, is reduced time to market."

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Ford designers have always worked globally, but the Global Studio has pulled them closer together.

Ford designers have always worked globally, but now the Global Studio has pulled them even closer together. Instead of packing up for a trip to Europe, a designer clicks on a telephone icon on a Silicon Graphics workstation, and is instantly sharing a three-dimensional design with his colleague across the world.

"It's not meant to be a large meeting where we discuss important issues," says Delena. "This is really one on one. It's one engineer talking to another, one designer talking to another, discussing a specific problem. It's something you can do right through your workstation and you really get problems resolved faster—much faster—that way. There's an interaction that you just don't get through the phone." You'll taste the effects of that interaction when you see the world-car styling of the 1996 Taurus. Its final look and feel were achieved by designers who met in the transatlantic cyberspace of the Global Studio.

The 1996 Ford Taurus exemplifies the world-car styling that Ford's designers, collaborating from around the globe, were able to achieve via the Global Studio

Ford designers received an unexpected bonus from Silicon Graphics technology: the ultimate MediaMail system. If it's too late to reach a colleague in real time, a designer can send a complete multimedia package of work—text, graphics, video clips—and send it overnight digitally with annotations. When the overseas designers come to work in the morning, they just open it up and point and click.

Where is this technology headed? Delena has a broad vision of distant, co-located colleagues and an altered global business culture.

"What do I think? I think this technology may open up new ways to accomplish the job. I think it's possible that in the future people working at home will be able to collaborate on design projects. Geographical locations won't matter. Decision-making will be more compressed in time. I think that this technology will work in synergy with others to provide the dynamics for a whole new way of doing business." ★

Grant Ellis (gellis@redshift.com) is a freelance writer who works from his Monterey Peninsula home.

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This image is not a photograph but was created using the Lightscape Visualization System from geometry created with AutoCAD.
Image courtesy of Advanced Graphics Applications

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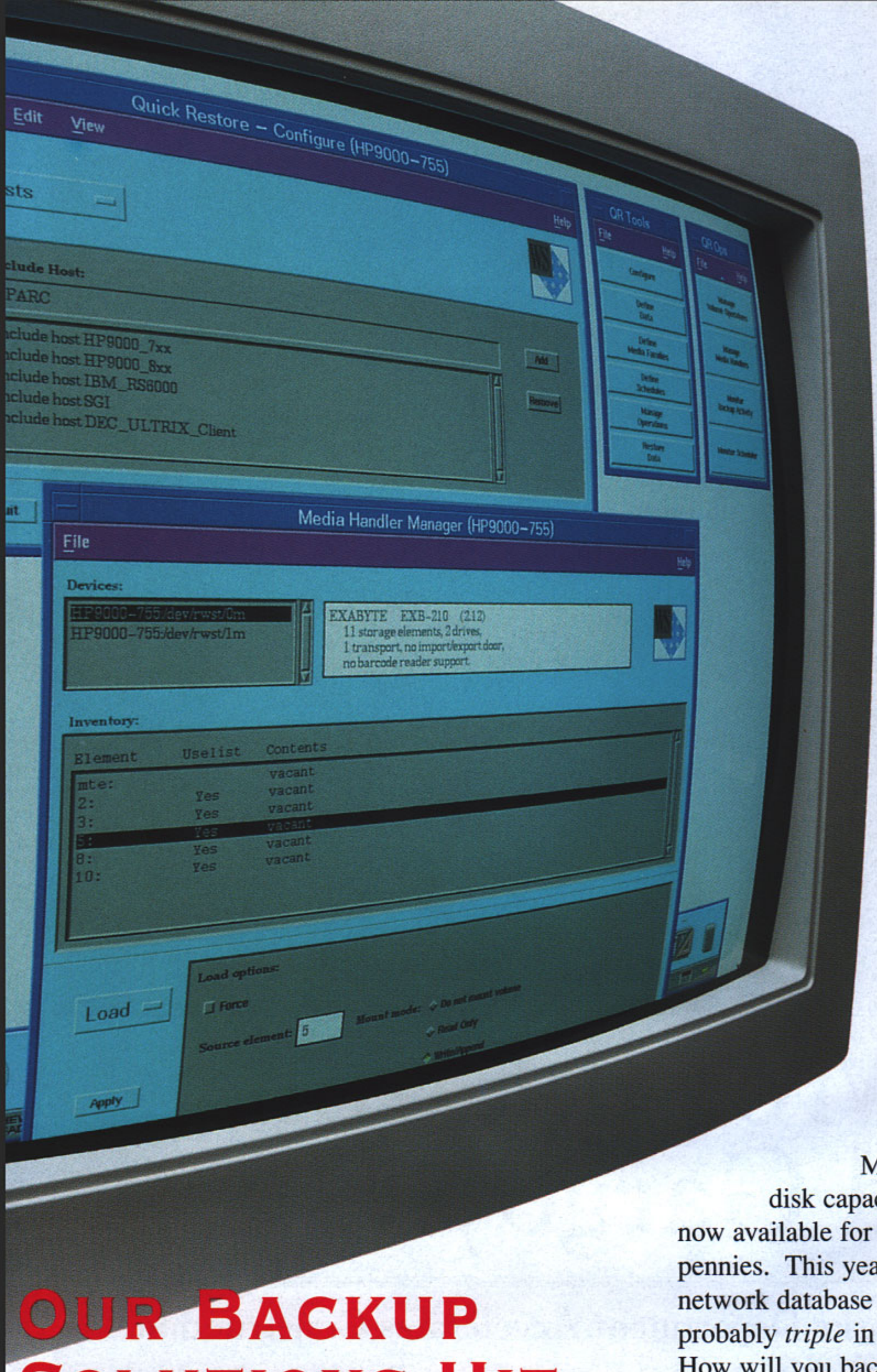


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Of Wrought Iron and Gargoyles

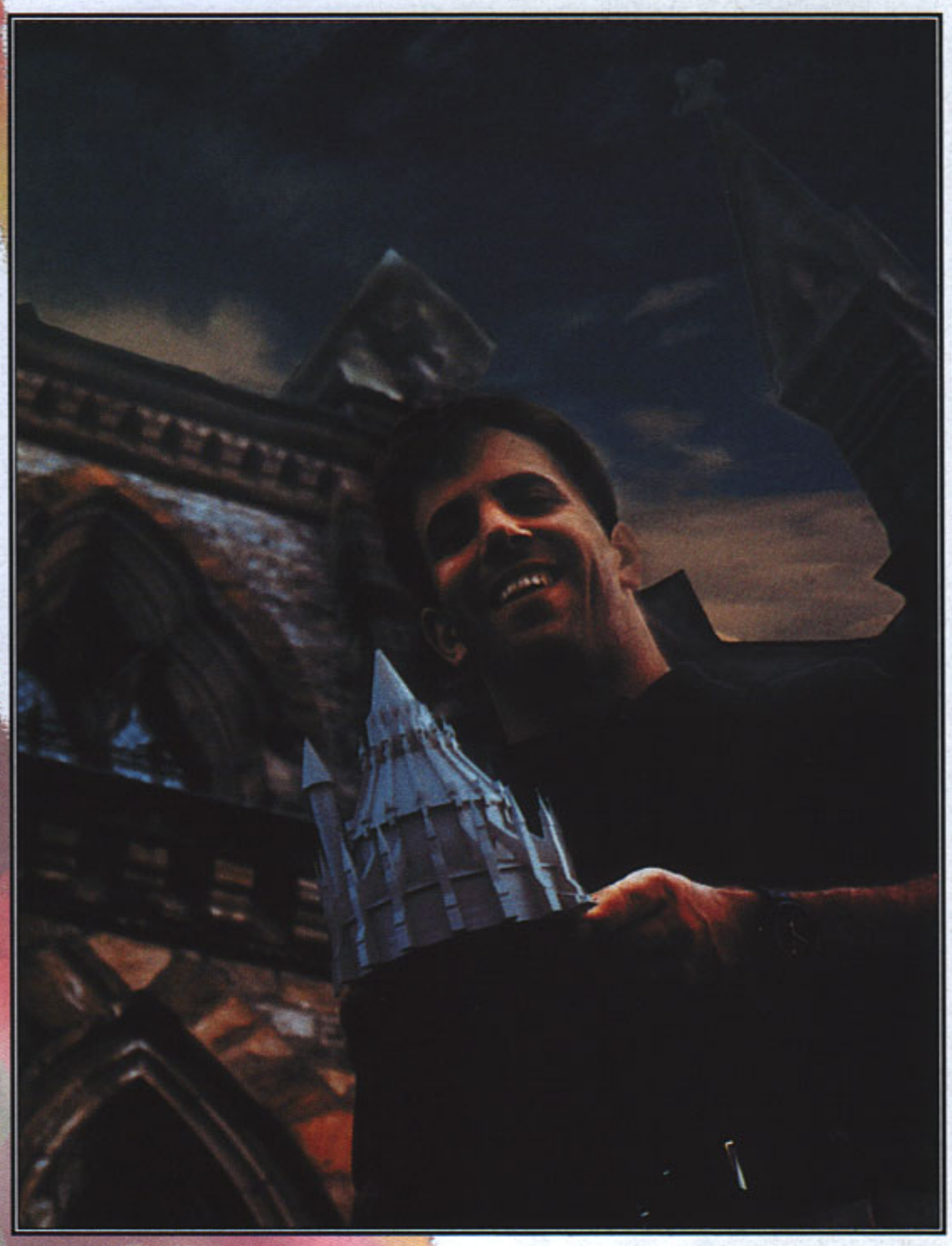
Canada's Public Works Department Accelerates Construction Planning, Melds the Old with the New, and Even Predicts the Impact of the Weather—All with the Help of Powerful Digital Tools.

by Lou and Robert Cobb

Step back in time and then walk into the future. Your tour begins as you approach the rugged stone facade of Canada's capital—the historical Parliament Hill Buildings in Ottawa. The green patina of the weathered copper roof glistens in the sun. Stains of 70 years trace intricate patterns down the walls, streaking the faces of hand-sculpted gargoyles. You walk among the five buildings on Parliament Hill and the 30 more across the street, moving in and out of the shadows cast by the early morning sun until you arrive at your destination—a renovated part of the Precinct. It fits smoothly into its surroundings, consistent to the finest architectural detail.

Stones and mortar? Far from it. You are watching an animation created by the Digital Simulation Laboratory under the Real Property Services within Public Works and Government Services Canada. The animation sequence was created on a Silicon Graphics Onyx RealityEngine workstation from a highly detailed three-dimensional digital model of the precinct. The images are a mix of the real and the imaginary, blended to pre-

At Left: Montage of the virtual model of the Parliamentary Precinct, courtesy of the Digital Simulation Laboratory/PWGSC
At Right: Francis Pelletier is the architect leading the Digital Simulation Lab Team. Photo: Andrea Burns



sent an eloquent picture of how proposed modifications will actually look.

Faster Review and Approval

Using architectural modeling on Onyx, the Digital Simulation Laboratory shows exactly how changes will appear and how they fit with the other existing buildings through a wide range of output modes, even making a detailed physical model in any scale in a fraction of the time it takes with traditional methods. This results in faster refinement of the design, examination and approval by the reviewing agencies, and, ultimately, in faster initiation of the construction project.

This is particularly valuable for Canada's 12-year program of modifications and enhancements to its Parliamentary Hill. Explains Francis Pelletier, Director of the Digital Simulation Laboratory (DSL), "Because of the precinct's historical significance, any changes must be reviewed and approved by many authorities. Using detailed texture mapping, we create a very realistic three-dimensional representation. Then using animation, we can move around and above the new areas so everyone can rapidly visualize exactly how it will appear. It really speeds up the approval process for major or sensitive projects such as the Parliamentary Precinct renovation."

3D Mandate

Created in 1992, the Digital Simulation Laboratory's mandate is to advance 3D technology and apply it to Canada's architectural and engineering needs. In particular, the DSL Team focuses on developing technologies to obtain output in as many forms as possible from a digitized image. Although the laboratory concentrates on government projects, it also accepts projects from the private sector if those projects have a significant research and development component that would advance its total capabilities.

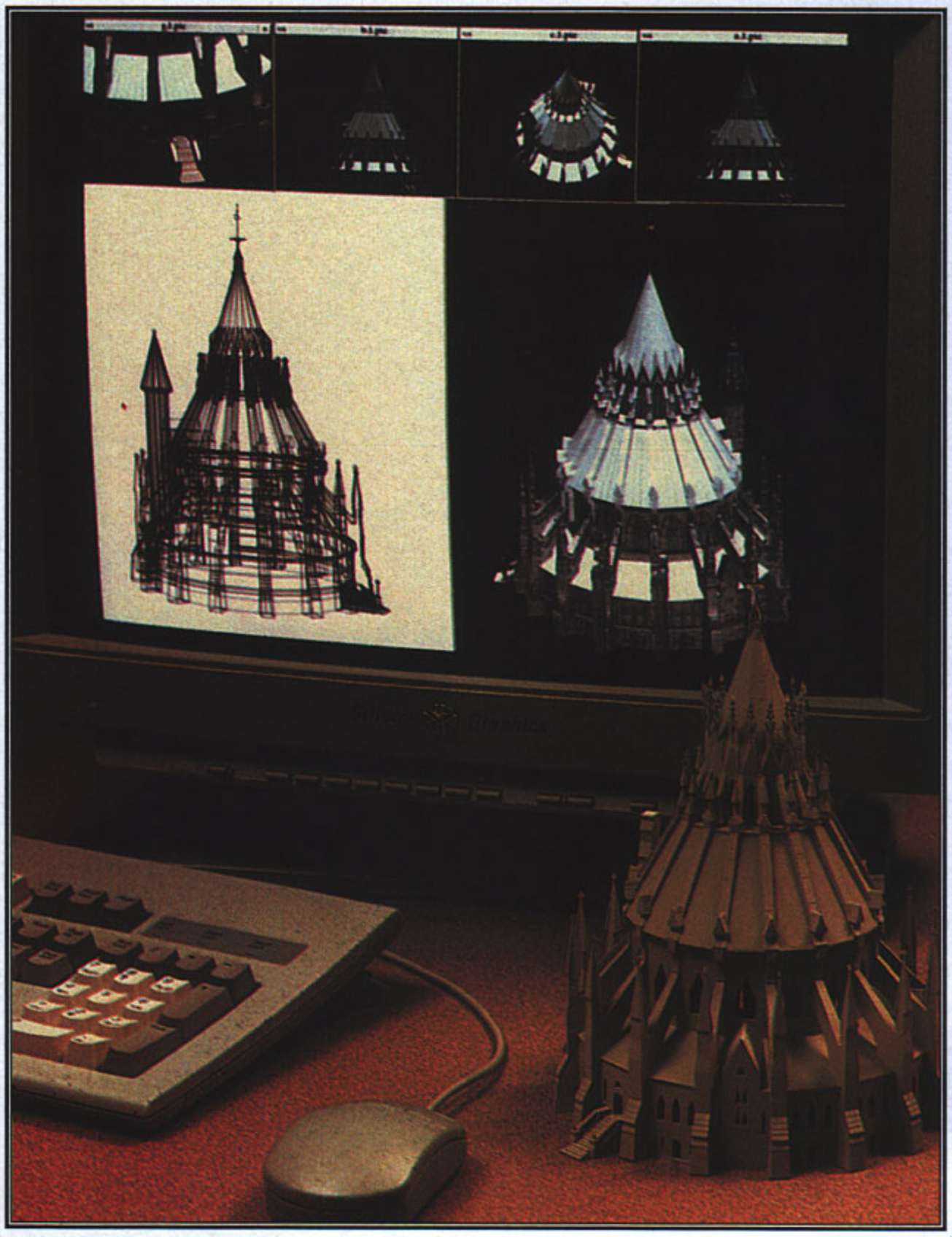
When establishing the laboratory, Pelletier and his team quickly found that Silicon Graphics was the clear choice for their demanding applications. "We did a benchmark study to evaluate which software was best for our immediate needs, as well as our future ones. A key factor was whether the software could handle our custom applications, such as a study of how the sun will cast shadows from the proposed structure. Every solid software package with the potential to meet our needs was only available on Silicon Graphics. That made the choice extremely easy," said Pelletier.

They selected a Silicon Graphics Crimson workstation, then soon added a Silicon Graphics Indigo workstation. Following the success of those systems, there was never any doubt about which vendor to choose when the time came to add more processing power to support the laboratory's steadily increasing requirements. In March, 1995, the laboratory purchased a Silicon Graphics Onyx RealityEngine^2, with 2GB of memory and 8GB of storage for large-scale projects such as the Parliamentary Precinct.

Currently, the laboratory has the three Silicon Graphics systems linked in a LAN, together with some Macintosh® workstations. The Silicon Graphics Onyx and Crimson systems each run SOFTIMAGE™ 3D software from Montreal-based SOFTIMAGE, while the Indigo workstation runs AutoCad®. The Macintosh provides initial photograph input and touch-up using the Adobe Photoshop™ software. Output capabilities include digital data-mix stereoscopy for real-time display animation, construction of physical models through stereolithography, stereoscopic slides, 3D rendering, and others. According to Pelletier, "We do all of the traditional tasks of architects except with fewer people. Plus, we can update our models much more quickly once they are built."

Researchers from the National Research Council (NRC) are taking data from the Digital Simulation Laboratory's computer files to create physical models accurate to a tenth of a millimeter, completed in just a few days. The technique is called rapid prototyping and employs laser beams to harden special resins into 3D shapes. According to Millan Yeung, of NRC's Institute for Advanced Manufacturing, scale reproductions can be made of the finest ironwork or the most complicated gargoyles, so long as this information has been stored in the original file. Other advantages are that it is easy to generate multiple copies and you can easily change the scale.

"This revolutionizes the architectural world, because it can compete with the modeling methods of skilled artisans," says Pierre Boulanger, a research officer with NRC's Visual Information Technology Laboratory. In the case of the



Stereo lithography is capable of reproducing fine detail from the digital simulation file. Photo: Digital Simulation Lab/PWGSC and Optima Communication

Parliamentary Precinct, it would have taken a skilled artisan nearly two months to make a single physical model, but NRC created it in only three days using the rapid prototyping techniques.

See the Shadow or Predict the Weather

The Digital Simulation Laboratory also worked with the NRC in pursuing one of mankind's most ancient dreams—to predict and control the impact of the weather. The Digital Simulation Laboratory can simulate various weather or seasonal conditions so you can actually experience the results of those conditions. For example, researchers can show how shadows will fall at any time of year so a proposed building can be designed to avoid overshadowing existing structures. Other simulations show how the wind will swirl around a proposed structure and where the snow might accumulate. These studies help architects design new buildings and engineers modify existing ones to better withstand the elements, an important advantage for Canada's military and government installations in the far northern reaches of the country.

Examples of such projects include an evaluation of the snow accumulation on the roof of the Naval Reserve station at Chicoutimi and whether a proposed building's design would dump snowdrifts into a parking lot at a National Defense project in Valcartier. A sun and shadow test was done for one of the proposed tourist pavilions in Ottawa across from

How to Visualize Architecture in 3D

The architectural 3D modeling process involves four phases:

- Information gathering
- Modeling
- Visualization
- Rendering

Information gathering involves collecting information from all available sources, including architectural plans, cross-sections, elevations, rectified pictures, photogrammetry, and aerial photographs. For existing buildings, professional photos taken with a consistent methodology for the camera angle, lenses, etc., are the primary source because of the rich information content and ability to capture detail.

The modeling stage rationalizes and integrates the different pieces of two-dimensional and three-dimensional information to create a 3D model. This is the longest and most exacting part of the process. For the Parliamentary Precinct, where the model must contain a very high level of surface detail and texture, the laboratory started creating the model a year ago for selected buildings. It expects to integrate the remaining information and complete the exterior of the entire 35 building complex within another four months. Finishing the interiors of the principal buildings will take an additional six months. When finished, the database of the model will be 3GB in size.

Visualization provides assistance to the camera in producing images from different angles. At this stage you can develop a storyboard for high-detail animation sequences by mapping the camera's movement around the model.

Rendering involves calculations from hundreds to thousands of images to create animated sequences. Architectural renderings provide a virtual reality environment that the viewer can explore using a monitor-control while wearing special glasses with polarized lenses. This technique is called dynamic stereoscopy and represents a building on the screen in such a way that you perceive depth and movement as if you were orbiting the structure or zooming in on particular details. Aspects of the structure which are not at all apparent from one perspective will appear as you move around to another point of view, just as if you were touring the location.

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This Model was built from an ultra-violet laser fusing a photosensitive resin.
Photo: Digital Simulation Lab/PWGSC and Optima Communication

Parliament Hill, between the Prime Minister's Bureau and the U.S. embassy to determine if the new structure would be overshadowed by the surrounding buildings. "The advantage of this technology is that you can apply it before the construction project is started and you can keep testing and making changes up to the end." says Pelletier.

Like Going to the Moon

The Parliamentary Precinct project is the largest and most challenging one the Digital Simulation Laboratory has faced. It has required all of the technological tools and expertise of the Laboratory. According to Pelletier, "For us, it's like going to the moon. It's not just doing a challenging project like the Parliamentary Precinct that is important, but as well, it's in expanding our knowledge. A project like this could not have been done with traditional modeling methods. The NRC's stereoscopic and stereolithography research, powerful Silicon Graphics machines, and SOFTIMAGE software made it possible for us to do this and make great progress in just a few months." ★

Lou and Robert Cobb are principles of The Write Idea, a marketing communications firm specializing in the client/server computer industry.

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F/X Breathes Life Into

By Kenneth Orville

W.C. Fields made it a rule never to act opposite of scene-stealing kids and small dogs. Had he seen Amblin Entertainment's *Casper*, my guess is he'd feel awfully similar toward ghosts.

In this summer's pristinely tuned vehicle for special effects animation, live actors take a far back seat to Industrial Light + Magic's quivering, shivering masses of ectoplasm. I'll make it simple: The ghosts are funny; the humans, not so much.

Director Brad Silverberg arranged it this way, though, giving his spooks all the great lines, while the earthly actors are around simply to set them up. The ghouls are Jerry Lewis; the people are Dean Martin. You get the picture.

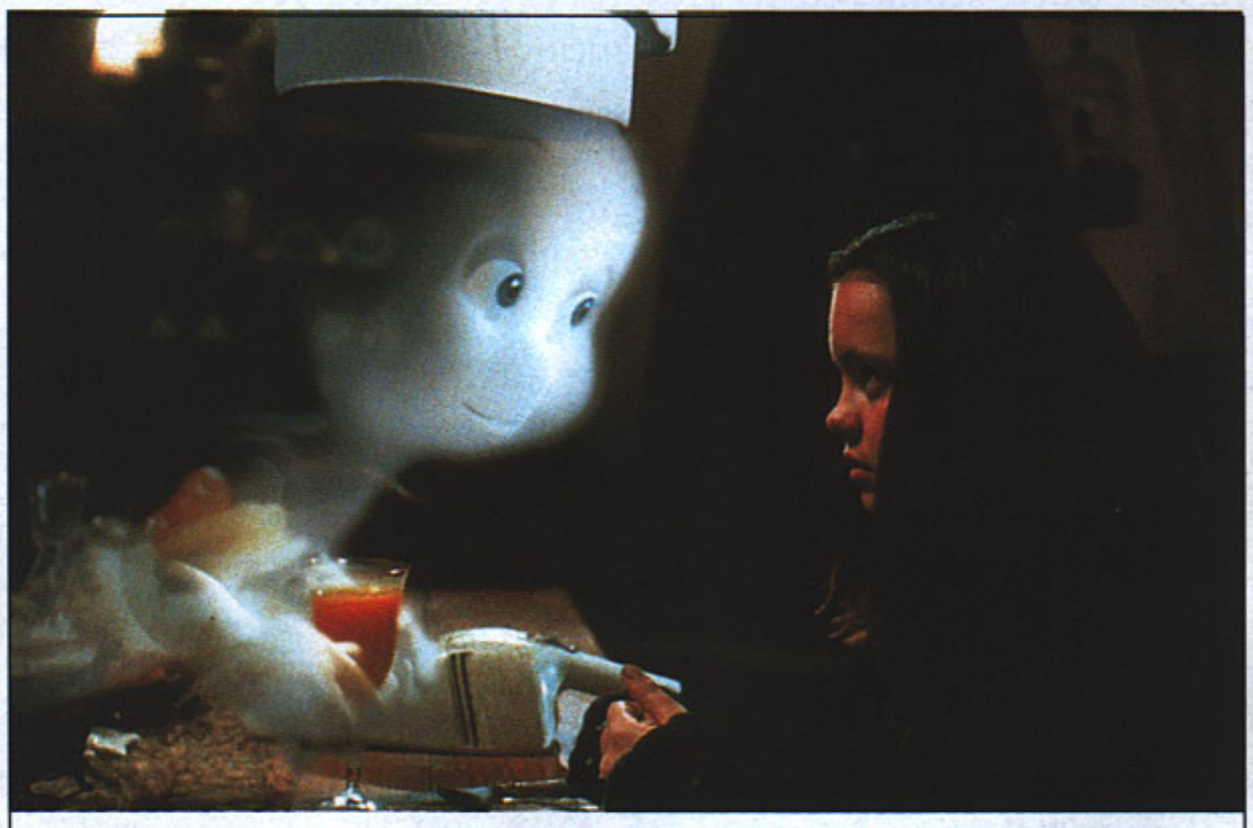

Image courtesy of Industrial Light + Magic

Casper is the story of a child ghost and two humans who bond with him. Bill Pullman (*While You Were Sleeping*, *The Last Seduction*) plays Dr. James Harvey, hapless therapist to the dead, who has dragged his unhappy but loving teenage daughter Cat (Christina Ricci, *The Addams Family I and II*) to nine different cities in the last two years. Every since Cat's mom died, the doc's been trying to help deceased souls "with unfinished business" move on to their final destination.

For those of us watching the movie, "your final destination" is what flight attendants use to refer to the city in which we get off the plane once and for all. In this movie, it refers to moving onto another plane entirely. But hey, we're not here to talk planes. We're here to talk ghosts.

So Cat and the doc are lured to Friendly, Maine, by bad guys Eric Idle (*Splitting Heirs*, every Monty Python film ever made) and Cathy Moriarity (*Matinee*). Moriarity is the evil one—she later inspires a Joan Riverseque animation of her own—with Idle nearby just to kick around. These people are bad, and they have determined that there is treasure in the old Whipstaff mansion, which Moriarity has just inherited. So they can search for the treasure without fear of ghostly harassment, they've hired Doc Harvey to flush out the undead from Whipstaff.

Casper, natch, is the headliner in this cryptic comedy. He's the wispy remains of Casper McFadden, the son of a quirky inventor who has spent the last century or so frozen as a 12-year-old, dead so long that he can't remember a thing about his human life.

Casper haunts his family's Whipstaff estate with three uncles, Stretch, Fatso, and Stinky. Like three dwarves outcast from Snow White, they are rude—downright abusive to young Casper—with Stretch tall and wisecracking, Stinky, short and odiferous, and Fatso, well, fat. So obese is he, in fact, that his largeness seems to enhance the immutable laws of physics: For every action upon his gelatinous surface there is at least one reaction—and commonly five or six.

Indeed, the ghosts are an animation tour-de-force. Curvaceous and milky, their fun, spectral forms are alternately smokey, squishy, watery, and rubbery. Dennis Muren and the crew at ILM must have made delicious sport of developing these four characters—their lively expressions, how they change their forms to accommodate suction attacks from vacuum cleaners, or diving down Pullman's gullet to set up cameo appearances by Hollywood stars.

Casper is an animation milestone in more ways than one. The film features

more than 44 minutes of special effects animation. That's an all-time record, just on sheer numbers alone. But the real bang comes from what ILM and the *Casper* production folks have *done* with that 44 minutes: They have created remarkably endearing digital movie stars.

If director Silverberg set out to prove that a collection of near-transparent blobs could out-act otherwise successful human actors, he's scored a bulls-eye with *Casper*. The scenes that string together the comparatively precious moments with the ghosts seem like just so much filler after a while. We're constantly on the edge of our seats, awaiting the boisterous catcalls of the transparent trio who shares its digs with Casper. Or we're longing for more face time with the friendly spirit himself, a character so sympathetic that you begin to resent even the hilarious uncles for the way they needle the poor kid. Even when humans alone populate the screen, they are cartoon wannabees, spending most of the film stumbling about production designer Leslie Diely's marvelous Whipstaff mansion, a crazy comics-inspired labyrinth of grand halls, secret passages, and creepy details.

Image courtesy of Industrial Light + Magic

Casper is also haunted by a lot of inside jokes. Pullman's character is named after the creator of the original *Casper* comic strip and founder of Harvey Comics. Cameos include a burnt-out exorcist (Saturday Night Live's Father Guido Sarducci, looking a bit like a ghost himself) and Ghostbuster Dan Akroyd. And the three uncles share a quick, Bowery banter reminiscent of the Marx Brothers, Hope and Crosby, or (ha, literally) the Dead End Kids.

By the time this review hits your mailbox, *Casper* will have flown out of your local cinema and will likely be available at the neighborhood video store. So is *Casper* worth renting? In a word: Youbetcha. See, kids have an amazing capacity to watch the same movie, like, a hundred times—to the point where you see them silently mouthing every word, from title to credits. Adults, unless suffering from a chemical imbalance, don't exhibit the same behavior. Yet, I didn't mind watching *Casper* twice in the theaters, and I expect we'll rent it again before the year is out.

Probably a good thing that W.C. Fields left us when he did: Against the likes of Casper and his three uncles, he wouldn't have stood a ghost of a chance. ★

Kenneth Orville belongs to the ages and lives in Dunville, Ontario, among other places.

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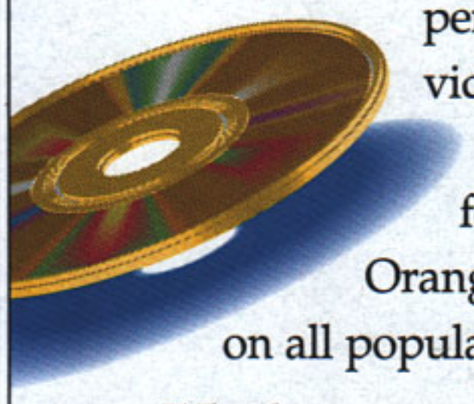

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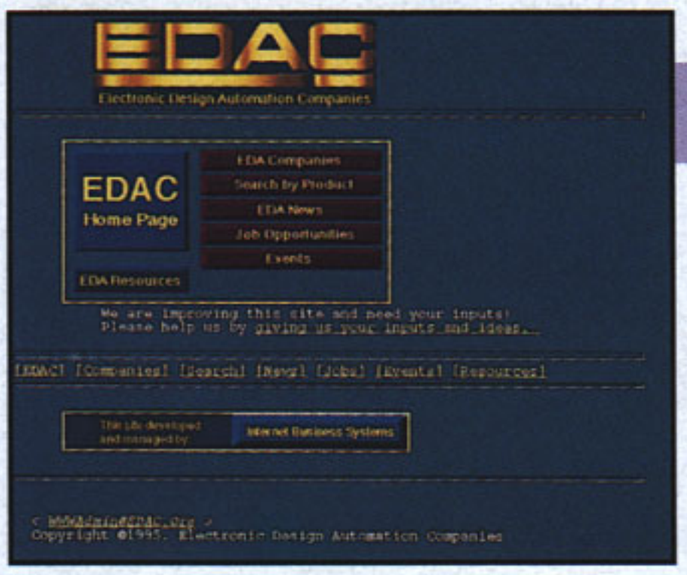
WEBOGRAPHY

A User's Guide to the WWW Galaxy

by Wendy Maurer

It is time once again for Webography. Our department editor, Wendy Maurer, sifts through piles and piles of particulars for you and pinpoints Web sites worthy of your attention. Recently, her excavations have uncovered sites for the computer-aided designer.



[http://www.edac.org]

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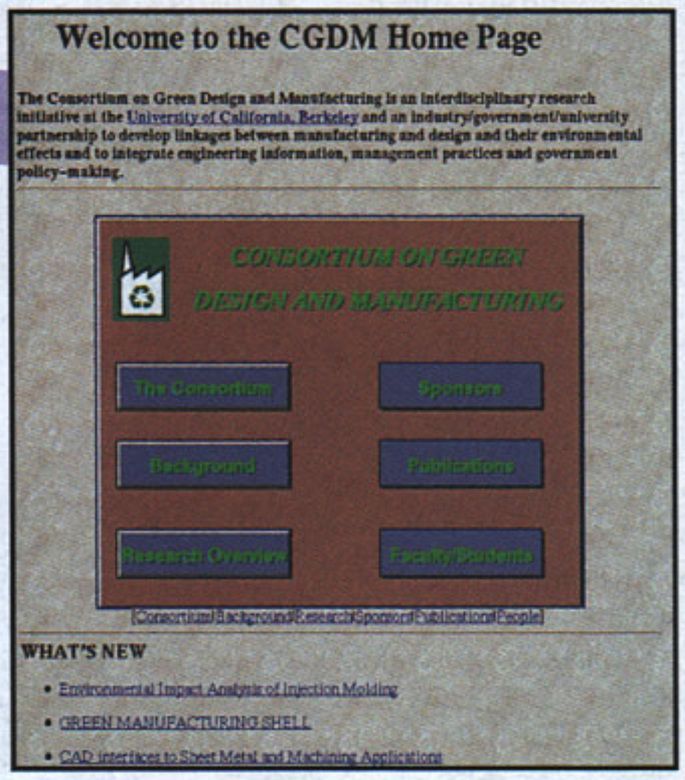
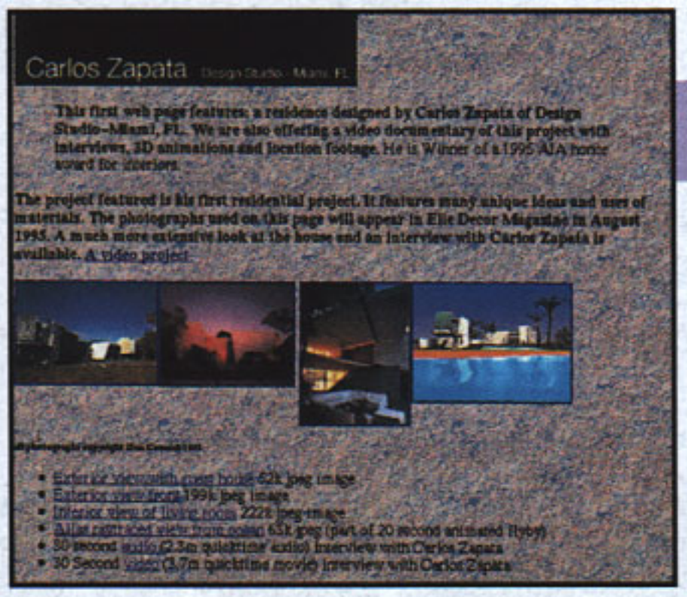
If you specialize in design tools for the electronic engineering community, put a bookmark at the Electronic Design and Automation Companies Web site. The EDAC site is a resource center featuring tools that increase productivity and decrease time-to-market. Here you'll find standards, new groups, publications, and universities specializing in creating automated design packages. There's also a link to the Special Interest Group on Design Automation (SIGDA) Web site, which provides current conference and activity itineraries, new group highlights, and membership information.



[http://euler.berkeley.edu/green/cgdm.html]

GREEN DESIGN AND MANUFACTURING

Historically, industries invest resources in developing the manufacturing process, while paying less attention to the environmental consequences of these decisions. The University of California at Berkeley is dedicated to eliminating this disparity through an association promoting environmentally-conscious planning, product design and manufacturing. The Consortium of Green Design and Manufacturing (CGDM) Web site provides project research focusing on waste, energy, disassembly, recycling, and disposal, as well as policy and regulations. CGDM is a commendable site deserving a visit from every designer and manufacturer dedicated to a healthy planet.



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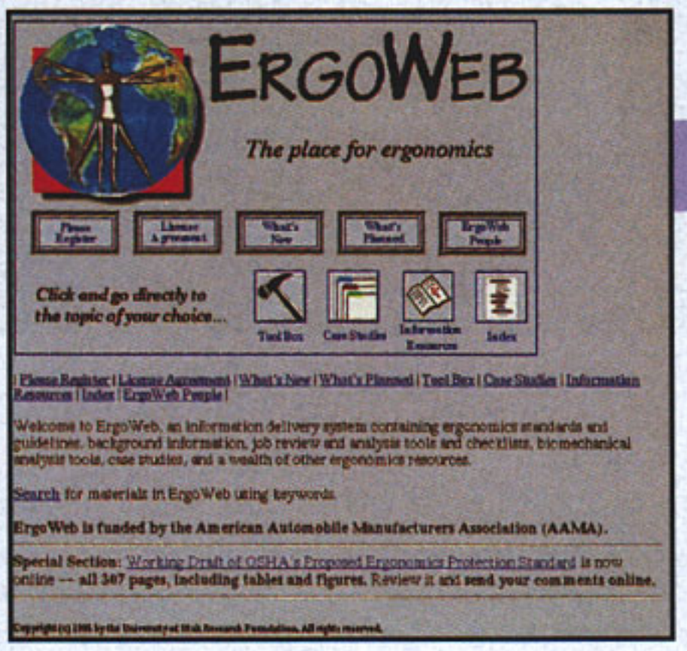
BUILDING BLOCKS

One of the only architecture Web sites to feature media 3D animations audio clips, and video documentaries in Design Architecture. This site is full of valuable resources as well as revolving exhibits from renowned architects. The current exhibit includes a residence designed by the recipient of the 1995 AIA honor award for interiors, Carlos Zapata, complete with interviews and location footage. You will also find other architecture links from neoclassical buildings of Atlanta and the design of energy efficient housing, to modeling and animation software resources.



[http://ergoweb.mech.utah.edu]

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These days, designing an ergonomically comfortable car is crucial. Drivers demand that everything be within reach -- the stereo, wiperblades, door locks, air conditioner button, even the glove box. The ErgoWeb site is all about ergonomic design. Sponsored by the American Automobile Manufacturer's Association, it is a resource for ergonomic examination. Whether you're designing cars, toasters, or athletic shoes, ErgoWeb provides you with the tools, case studies, standards, and guidelines to make your design work. The ErgoWeb toolbox has various checklists to measure ergonomic, metabolic, cumulative trauma, and material handling risks. Case studies discuss the impacts of headlamp, windshield, and brake design. Ergo designers can also get information about conferences, periodicals, and reference books.

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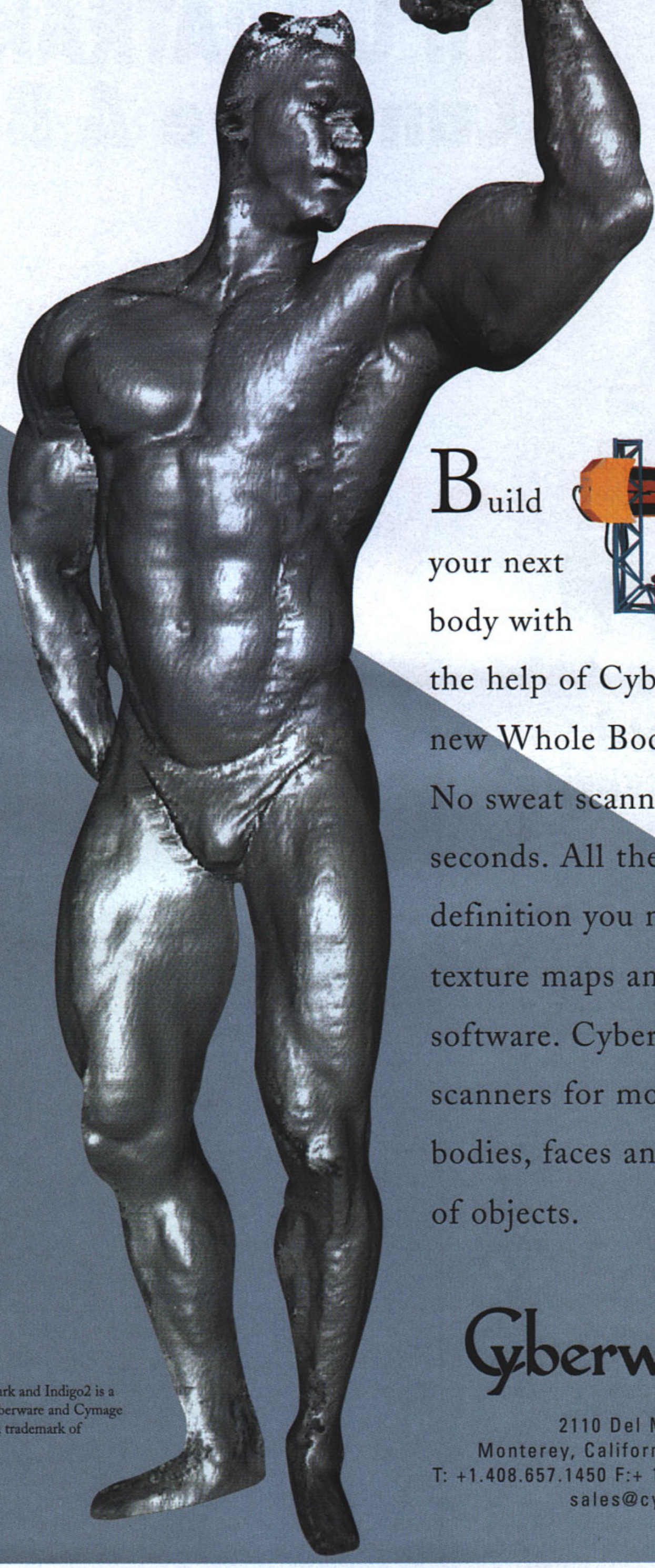
INNOVATION, COLLABORATION, AND VALIDATION

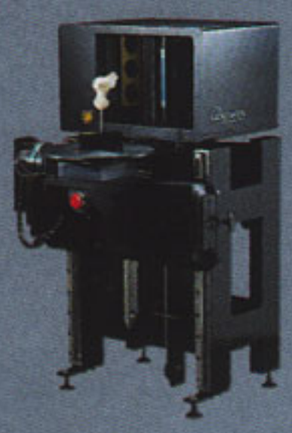
We would be remiss if we failed to mention design without manufacturing. The godfather of all Web resources for manufacturers is the SiliconWorks web site. It has all of the resources you would expect -- industry news, publications, training, professional societies, and a calendar of events -- and more. Scour the latest innovative technologies such as visual and global manufacturing, design simulation, and product design verification. For those serious about competitive manufacturing, SiliconWorks should not be missed.

Wendy Maurer lives in a small fishing cottage in the hills of Sausalito and writes primarily about the Internet and other sophisticated technologies.

Body Building



The body builder's image began as a 17 second scan. The body builder posed on the platform of Cyberware's new WB4 Color Whole Body Scanner. The WB4 is now available for sale and demonstration. $410,000.



Cyberware also provides color 3d scanners for faces and objects. The 3030/MM scanner pictured above scanned a toy tiger to quickly produce this detailed 3d model. $75,200.

Model courtesy Cyber_Site Europe, +44 81 573 1526

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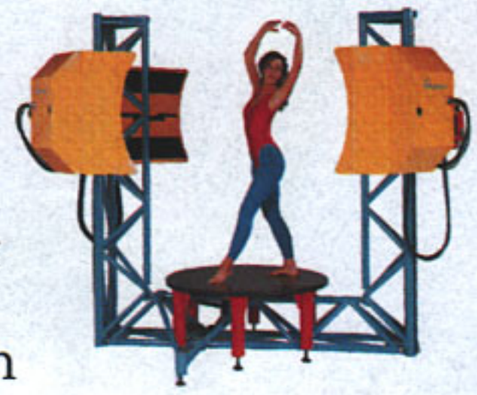

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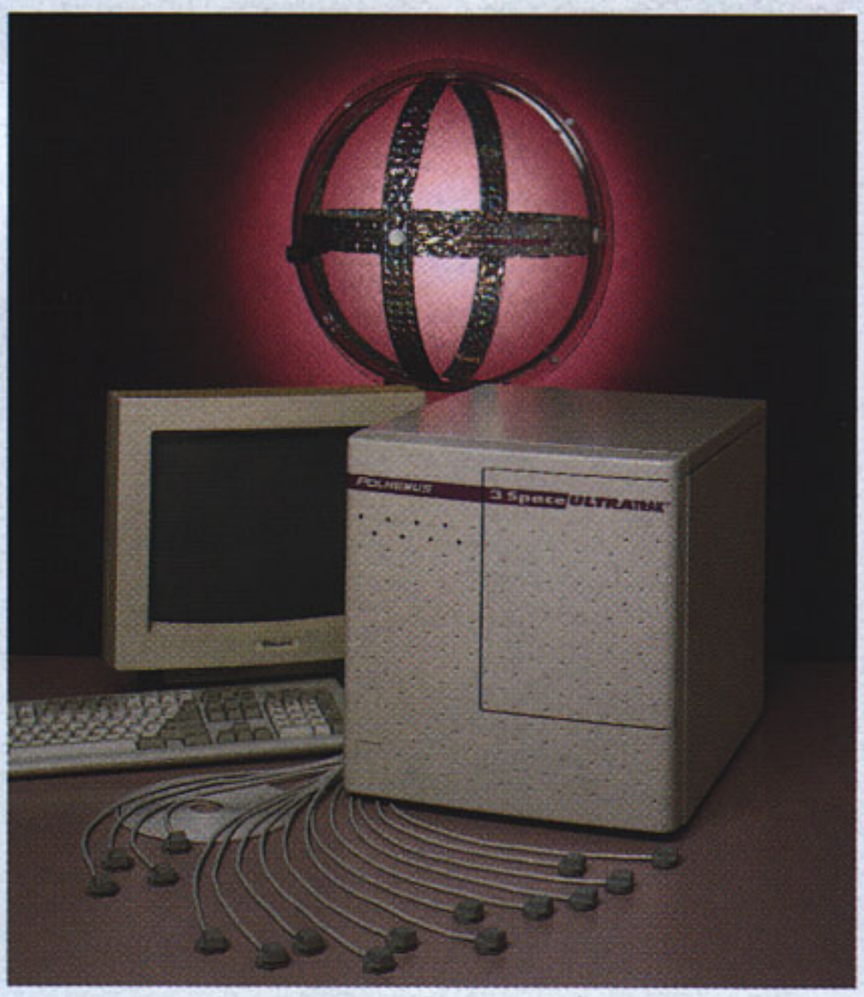

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ROTATION IN 3 DIMENSIONS

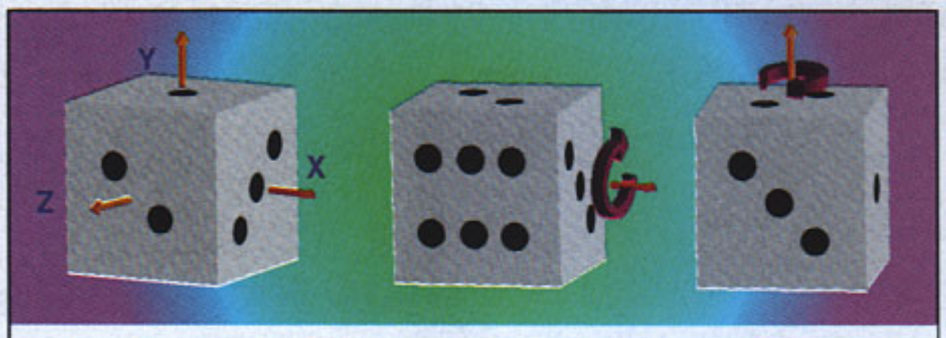
By Tom Davis

Rotation is one of the most confusing topics for beginners in 3D computer graphics. It's an intrinsically difficult subject, and there are many ways to approach it.

It is particularly difficult using the old GL™ graphics library, whose interface provided only for rotations about the coordinate axes. In OpenGL® rotations are specified about an arbitrary axis.

To understand a 3D concept, it's often easiest to thoroughly study the situation in 2D first. Operations such as scaling and translation trivially extend to 3D.

Rotations are more difficult; in particular, rotations do not commute—rotation R_1 followed by rotation R_2 is usually different from rotation R_2 followed by R_1. Even the result of combining simple rotations can be quite unintuitive. Figure 1 illustrates a 90-degree rotation about the x axis followed by a 90-degree rotation about the y axis. The combination is a 120-degree rotation about the axis x=y=z. Thank goodness we don't live in a 4D Euclidean space or no one would ever figure it out.



The die on the left is rotated 90° about the x-axis, yielding the die in the middle. Then a 90° rotation about the y-axis yields the die on the right.

There's more than one way to think about rotation, and different problems require different approaches. In this article we'll consider rotations about the origin described in terms of axis transformation, angle-axis, and quaternions. (To rotate about a point other than the origin, translate it to the origin, rotate, and translate back.)

We'll use these definitions:
Unit vector: vector having length 1. "Normalizing" is dividing a vector by its length, making a unit vector.
Cross-product: a product of two 3D vectors giving another:
$(x_1,y_1,z_1)\times(x_2,y_2,z_2) = (y_1z_2-z_1y_2, z_1x_2-x_1z_2, x_1y_2-y_1x_2)$.
Dot product: a product of two vectors giving a scalar:
$(x_1,y_1,z_1)\cdot(x_2,y_2,z_2) = x_1x_2+y_1y_2+z_1z_2$.

I'll use row vectors as in the old GL, since they can be printed more compactly. To convert to OpenGL column vectors, simply transpose all the vectors and matrices, and reverse the order of multiplication.

Axis Transformation

Any rotation about the origin maps the x, y, and z axes to three mutually perpendicular unit vectors. The coordinates of these vectors form the rotation matrix. If a rotation maps:
$(1,0,0)$ to $(x_1\ y_1\ z_1)$
$(0,1,0)$ to $(x_2\ y_2\ z_2)$
and $(0,0,1)$ to $(x_3\ y_3\ z_3)$,
then its rotation matrix is:

$$\begin{vmatrix} x_1 & y_1 & z_1 \\ x_2 & y_2 & z_2 \\ x_3 & y_3 & z_3 \end{vmatrix}.$$

Matrices of this form are orthogonal; their inverse is their transpose. In other words, the matrix that rotates in the opposite direction, taking (x_1,y_1,z_1) to $(1,0,0)$, and so on, is:

$$\begin{vmatrix} x_1 & x_2 & x_3 \\ y_1 & y_2 & y_3 \\ z_1 & z_2 & z_3 \end{vmatrix}.$$

Using this fact, it's easy to find the rotation that takes any oriented set of three mutually perpendicular vectors to any other three—transform the first set to the unit vectors, and then transform the unit vectors to the other set. For example, the matrix representing the transformation taking:
$(x_1\ y_1\ z_1)$ to $(X_1\ Y_1\ Z_1)$
$(x_2\ y_2\ z_2)$ to $(X_2\ Y_2\ Z_2)$
and $(x_3\ y_3\ z_3)$ to $(X_3\ Y_3\ Z_3)$
is the following matrix product:

$$\begin{vmatrix} x_1 & x_2 & x_3 \\ y_1 & y_2 & y_3 \\ z_1 & z_2 & z_3 \end{vmatrix} \begin{vmatrix} X_1 & Y_1 & Z_1 \\ X_2 & Y_2 & Z_2 \\ X_3 & Y_3 & Z_3 \end{vmatrix}.$$

In fact, you only need to know where the x and y axes go — the z axis is the cross-product of the x and y axes.

Angle-Axis

Quite often, rotations are expressed as a rotation by an angle about some axis.

In 2D, it's simple; there's only one axis, and a rotation by t is acheived by the following matrix multiplication:

$$(x, y) \begin{vmatrix} \cos t & \sin t \\ -\sin t & \cos t \end{vmatrix} = (x \cos t - y \sin t,\ x \sin t + y \cos t).$$

One can also think of points on the plane as complex numbers, x+yi, where i is the imaginary $\sqrt{-1}$, so $i^2 = -1$. Multiplying x+yi by the complex number $\cos t + i \sin t$, gives $x \cos t - y \sin t + (x \sin t + y \cos t)\,i$, which shows that a complex multiplication is equivalent to the matrix multiplication above.

The standard power series:
$e^x = 1 + x + x^2/2! + x^3/3! + x^4/4! + \ldots$
$\sin(x) = x - x^3/3! + x^5/5! - x^7/7! + \ldots$
$\cos(x) = 1 - x^2/2! + x^4/4! - x^6/6! + \ldots$
are related. In fact, if we replace x with i t, and recall that $i^2=-1$:
$e^{it} = 1 + i\,t - t^2/2! - i\,t^3/3! + t^4/4! + \ldots$
$e^{it} = 1 - t^2/2! + t^4/4! - \ldots$
$\quad + i(t - t^3/3! + t^5/5! - \ldots)$
$e^{it} = \cos t + i \sin t.$

So multiplication by e^{it} rotates a complex number by an angle t.

Let $S = \begin{vmatrix} 0 & 1 \\ -1 & 0 \end{vmatrix}$.

S is like i in that $S^2 = -I$ (the identity matrix). Plugging the matrix tS into the equations for e^x, sin(x), and cos(x), and replacing "1" by the identity matrix I, gives:

$e^{tS} = I \cos t + S \sin t$, or:

$e^{tS} = \begin{vmatrix} \cos t & \sin t \\ -\sin t & \cos t \end{vmatrix}$,

the 2D matrix representing a rotation by the angle t.

Now we'll look at 3D rotations about the (normalized) axis v = (x,y,z).

If we were only interested in 3D rotation about the x-axis, we could simply add a row and column of zeroes to the matrix S above, giving:

$S' = \begin{vmatrix} 0 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & -1 & 0 \end{vmatrix}$,

And, as before, $e^{tS'}$ would be the standard 3D rotation matrix about the x-axis. If R is a matrix that rotates the x-axis to (x,y,z), then $R^{-1}e^{tS'}R$ represents an rotation by t about the axis (x,y,z). But $R^{-1}e^{tS'}R = e^{tR^{-1}S'R}$).

Using the axis transformation ideas from the first part of this article, one can find the matrix R that maps (x,y,z) to (1,0,0), that maps a unit vector perpendicular to it (I normalized (z-y,x-z,y-x)) to (0,1,0), and that maps their cross-product to (0,0,1).

$S = R^{-1} S'R = \begin{vmatrix} 0 & -z & y \\ z & 0 & -x \\ -y & x & 0 \end{vmatrix}$,

so the general 3x3 rotation matrix R is given by the formula e^{tS}.

Let $U = v^T v = \begin{vmatrix} x \\ y \\ z \end{vmatrix} \begin{vmatrix} x & y & z \end{vmatrix} = \begin{vmatrix} x^2 & xy & xz \\ xy & y^2 & yz \\ xz & yz & z^2 \end{vmatrix}$.

To evaluate e^{tS}, it's easy to multiply S by itself and verify that $S^2 = U-I$, and $S^3 = -S$. Using these identities in the series for e^x, cos(x), and sin(x), we obtain the following formula for the rotation matrix:

$e^{tS} = U + (I-U) \cos t + S \sin t$.

Quaternions

Now we know how to construct a rotation matrix from angle and axis. But if rotations are stored in angle-axis form, then how can they be combined to find the resulting angle and axis?

When 2D rotations are expressed using complex numbers, they're combined with multiplication. Quaternions let you do the same thing in 3D.

Complex numbers are made by adding $i = \sqrt{-1}$ to the real numbers. To make the quaternions, augment the real numbers with three different imaginary numbers, i, j, and k, satisfying the relationship $i^2 = j^2 = k^2 = ijk = -1$. The most general quaternion has the form a + bi + cj + dk, where a, b, c, and d are real numbers. Be careful with the order of multiplication; ij = -ji, for example. In fact, from the relation above, we can work out the quaternion multiplication table:

ij = -ji = k, ki = -ik = j, and jk = -kj = i.

i, j, and k behave exactly like the unit vectors along the x, y, and z axes under the cross product. Here is a sample quaternion multiplication:

(2 + 3i + j)(1 + j + k) = 2(1+j+k) + 3i(1+j+k) + j(1+j+k) = 2 + 2j + 2k + 3i + 3ij + 3ik + j + j^2 + jk = 2 + 2j + 2k + 3i + 3k - 3j + j -1 + i = 1 + 4i + 5k.

If the unit vector (x, y, z) is the axis of rotation, and t is the angle, then use the quaternion:

cos *t*/2 + sin *t*/2 (xi + yj + zk)

to represent the rotation. Combine two different rotations about the origin by multiplying the corresponding quaternions. For example, if R_1 is a rotation of 90 degrees about the x-axis and R_2 is a rotation of 90 degrees about the y-axis, the corresponding quaternions are:

R_1: cos(45°) + sin(45°) i

R_2: cos(45°) + sin(45°) j

cos(45°) = sin(45°) = $\sqrt{2}/2$, so

$R_1 R_2 = .5(1 + i + j + ij) = .5 + .5(i + j + k)$

$= \cos(60°) + \sin(60°) (i/\sqrt{3} + j/\sqrt{3} + k/\sqrt{3})$

The combination is a rotation of 120 degrees (120/2 = 60) about the axis x=y=z. See figure 1.

William Rowan Hamilton introduced the quaternion notation using i,j, and k in 1843. If you don't like the i,j,k-stuff, you can express the same thing in terms of 3D vectors, and multiplication in terms of dot- and cross-products: A quaternion is a pair consisting of a scalar s (the real part of the quaternion) and a 3D vector v (the imaginary part): (s, v). If (s, v) and (t, u) are two quaternions, define the product to be:

(s, v) (t, u) = (st-v·u, su + tv + v x u).

If the unit vector v is the axis of rotation, and t is the rotation angle, then the corresponding quaternion is given by:

q = (cos *t*/2, sin *t*/2·v).

It is easy to check that this representation of the rotation quaternion is exactly equivalent to Hamilton's form above in terms of i, j, and k.

It's easy to check that inverse of the rotation quaternion q is:

q^{-1} = (cos *t*/2, -sin *t*/2·v) since $q\, q^{-1} = (1, 0)$.

To rotate an arbitrary point p by the angle t about the axis v, the result is the imaginary part of:

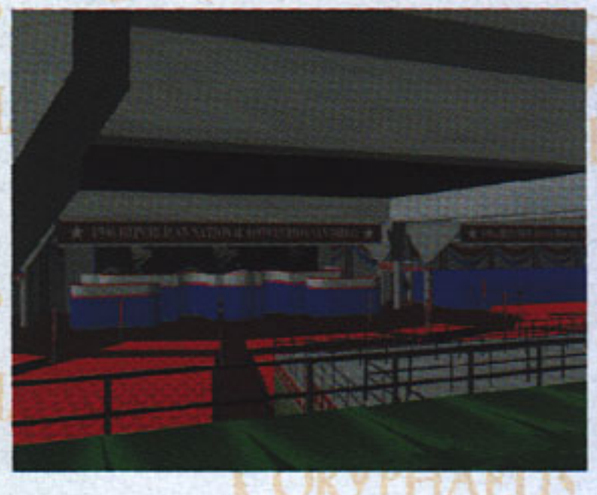
$q^{-1}(0,p)q$.

A couple of nice references for rotation (especially quaternions) can be found in:

Shoemake, Ken, Animating Rotation with Quaternion Curves, SIGGRAPH Proceedings, 1985 pp. 245-252.

Misner, C, Thorne, K, and Wheeler, J, Gravitation, W.H. Freeman and Company, San Francisco (1973). Chapter 41.★

Tom Davis (davis@asd.sgi.com) is a principal scientist at Silicon Graphics where he works as a graphics hacker and mathematician-gone-bad. He has worked on everything from GL™ and OpenGL® to the Showcase™ and Jot™ applications.



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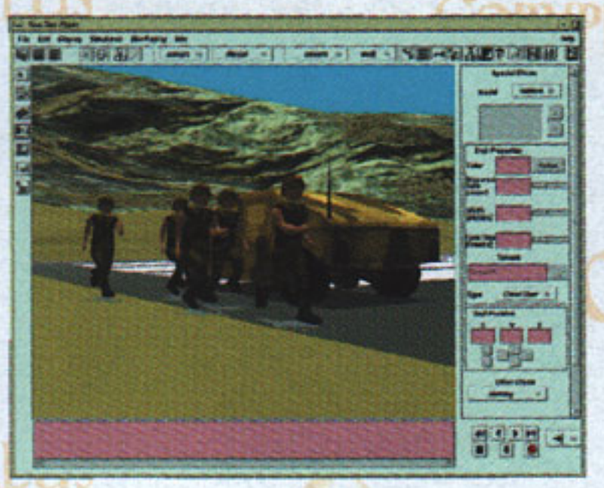

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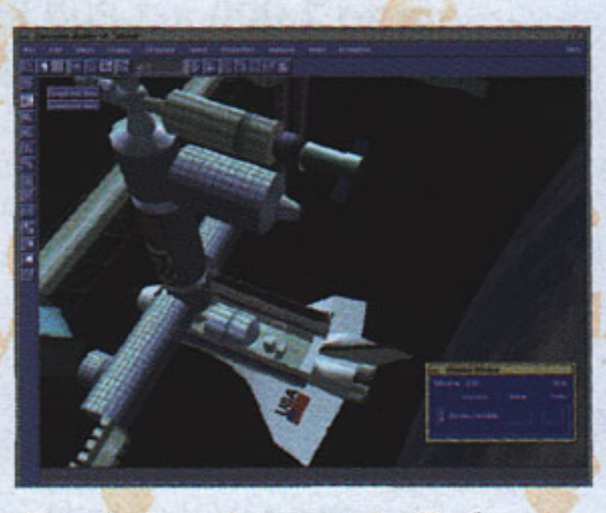

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RANDOM NOTES

PARADIGM SIMULATION'S VEGAMARINE

We begin this edition of Random Notes from the Field by going far out to sea. Well, this is only a simulation, brought to you by the folks at Paradigm Simulation Inc. in Dallas, Texas. Paradigm has announced the VegaMarine module for its Vega visual simulation software. Using VegaMarine and a Silicon Graphics workstation, you can easily create a lifelike maritime simulation. The program generates a real-time dynamic ocean surface, modeled as a textured 3D surface with user-definable wave heights and periods. Suppose you're trying to create a simulation to clean up an oil spill in an inlet. You can create ocean waves, floating buoys and booms, eddies, stern wakes, constant tension lines, and constant distance lines, and even toss a crew member overboard. And, of course, you can do all of this using a point-and-click interface or a C API. Easier than coming about in a stiff wind in the middle of San Francisco Bay. Enzian Technology is currently using VegaMarine to upgrade training modules for the Navy's Surface War Officer's School in Newport, RI. For information, call (214) 960-2301.

POLHEMUS' INSIDETRACK VR TRACKER

Polhemus in Colchester, Vermont, stunned the virtual reality biz recently when it slashed the price of its INSIDETRACK 6 Degree-of-Freedom VR tracker to $999 from $2,250. That makes INSIDETRACK the first 6 DoF tracker to be priced under $1,000. INSIDETRACK is a 3D position/orientation sensing device that tells a computer which direction a VR user is looking and which direction he or she is turning. INSIDETRACK's sensor is mounted on a board that can be plugged into the ISA slot of any computer. For information, call (802) 655-3159.

NEW VR SOFWARE RELEASES FROM DIVISION

While on the topic of things virtual, Division, Inc. in Chapel Hill, NC, just rolled out a couple of hot new software releases to speed up and simplify the development of sophisticated VR environments for professional applications. The programs, dVS 3.0 run-time software and dVISE 3.0 authoring system, make it possible for mere mortals to create whizzy VR environments without knowing anything about programming. According to Division, dVS is the only VR run-time software that runs in parallel with user applications, allowing people to create virtual worlds faster and more easily. The program's device multiple server architecture provides device-independent servers for image generation, spatialized audio, collision detection, input/output device control, object motion constraints, and physical simulation. The new release adds multiuser networking, so several

people on a LAN or WAN can work together in real time in a virtual environment. Division devised dVISE 3.0 with a simpler icon-based GUI, 3D tools to allow people with a head-mounted display in a virtual environment to make changes from within the environment, and 30 preprogrammed event types that can trigger more than 70 built-in action functions. The program also offers keyframe animation to let people create animated sequences that run along with selected events in the virtual environment. dVS starts at $2,000. The dVISE Virtual Design Environment costs $6,000 and the dVISE Programming Developers Toolkit costs $4,000. For information, call (919) 968-7797.

MERGER BETWEEN ADEPT AND SILMA

Adept Technology Inc. in San Jose, California, a maker of industrial controls, robots, and automation software, has merged with SILMA, Inc. in Cupertino, California SILMA makes automated manufacturing software that is used by automotive, consumer electronics, and aerospace companies. "Adept is committed to reducing the time and cost of implementing flexible automation technology," said Brian Carlisle, Adept's president and co-founder. SILMA's products simplify the planning and testing of automation equipment and increase manufacturing productivity. The combined companies will employ about 300 people with expected annual sales of about $62 million.

SILICON GRAPHICS COLLABORATION WITH OXFORD/GLAXO

Silicon Graphics will work with Oxford Medical Group PLC in Oxford, England to support Oxford's collaboration with Glaxo Wellcome PLC in London in developing molecular modeling software that will accelerate Glaxo's drug development process. Silicon Graphics will loan workstations and peripherals to the Oxford/Glaxo effort, along with development software and maintenance services. Oxford and Glaxo are jointly developing custom drug-design

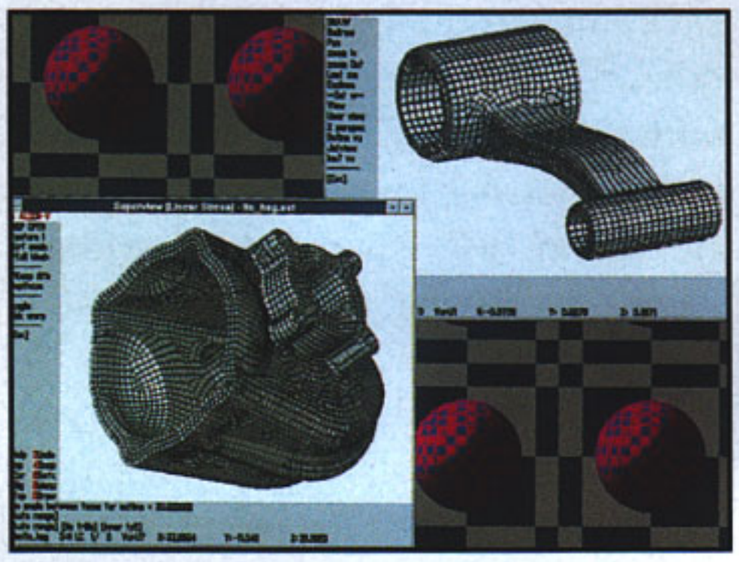
software that Glaxo will use in its drug development worldwide. The first stage of the project calls for the two to develop software for an integrated structural activity relationship (SAR) system. Subsequent projects may include the development of advanced visualization tools and additional SAR tools.

NEW HANDBOOK AND SOFTWARE FROM EXTRON

On the education front, Extron Electronics in Anaheim, California has released its new *Handbook of Computer Interfacing Vol. IV*, a guide to the most important elements of computer interfacing. Extron is also making available software that was used in the Projection Shoot Out at the most recent INFOCOMM, 95 show in Dallas. The Shoot-Out software runs a series of comparison tests on large display screens. it costs $99. For information, call (800) 633-9876.

SPEED MESH SERVICE FROM ALGOR

Algor Inc., (no relation to the vice president of the United States), Pittsburgh, Pennsylvania is offering a new time-saving service to convert CAD solid models to finite element meshes of eight-node hexahedra ("bricks"). Algor's Speed Mesh service uses the company's Houdini automatic brick element mesh generator for the conversion. The company can convert CAD solid model files from a variety of CAD systems and generate models for all commonly used finite element analysts (FEA) software products. "Most engineers today build their models with CAD solid modelers and then must convert the models for finite element analysis," said Michael Bussler, Algor's president. "Outsourcing finite-element model building speeds up the process, allowing engineers to focus their efforts on engineering issues."



INDUSTRIAL PHOTOGRAMMETRY SOFTWARE PACKAGE FROM VEXCEL

Uexcel Corporation of Boulder, Colorado has announced the release of FotoG-FMS, an advanced industrial photogrammetry application. The software product allows users to produce accurate 3D models of congested plant environments or obtain precise 3D coordinates at critical plant locations by taking photographs of the facility and then processing them using the software. The software does not require extensive photogrammetric expertise or specialized equipment to operate. FotoG-FMS has been designed to be efficient in support of small revamp projects as well as large 3D plant models.

The Foto-G FMS software system runs in the MicroStation CAD environment on Silicon Graphics workstations, other UNIX hardware, and Windows NT-based hardware. Using photogrammetry reduces the need for costly, time-consuming on-site visits by engineering and other technical personnel by limiting on-site activity to a brief photography session. Plant operation interruptions are reduced and efficiency and safety is increased by allowing the majority of the "as-built" process to be performed in an office environment. FotoG-FMS software allows independent engineering firms to benefit from the advantages of photogrammetry without relying on outside organizations or investing in special hardware.For more information, call (303) 444-0094.

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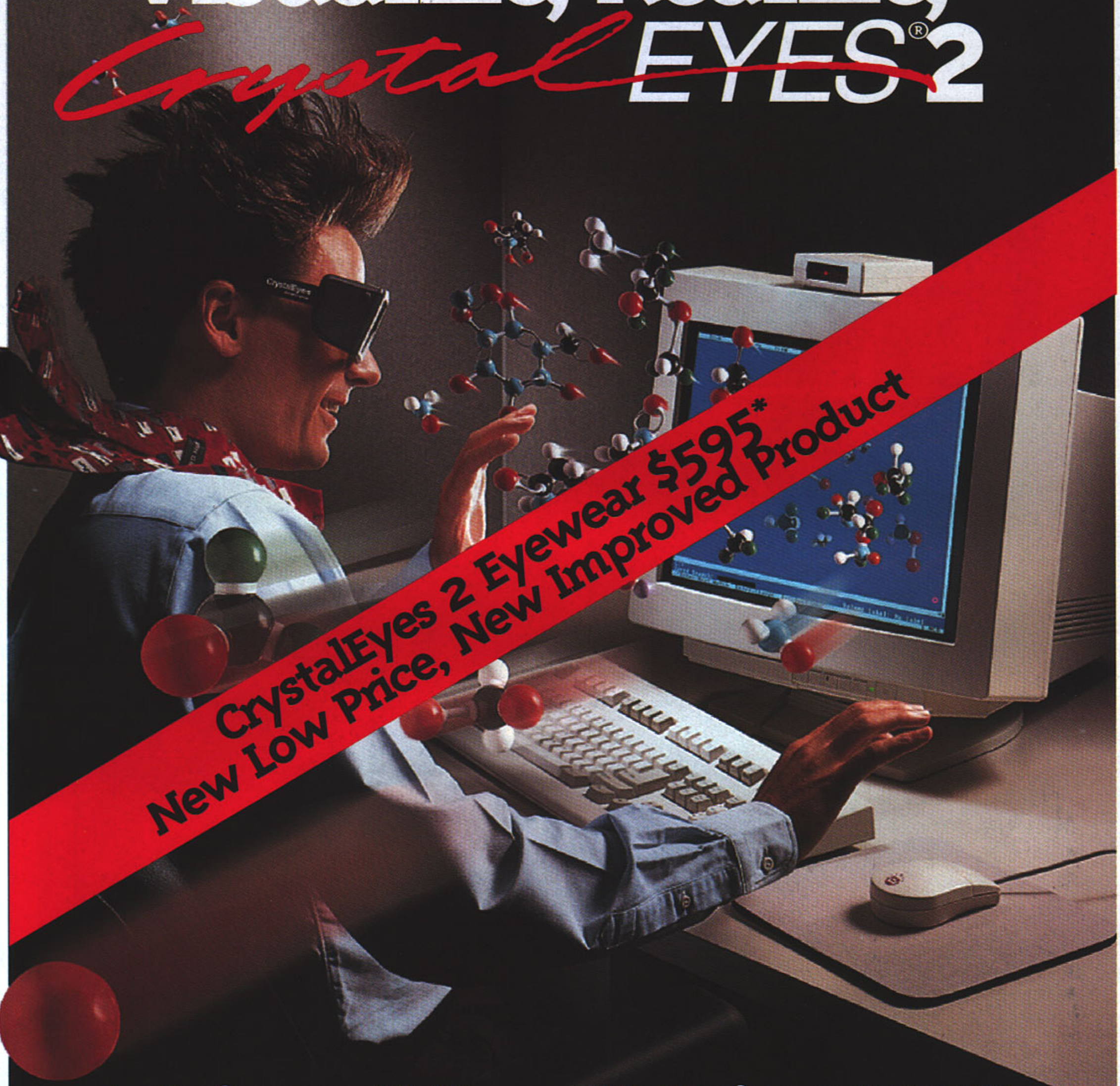

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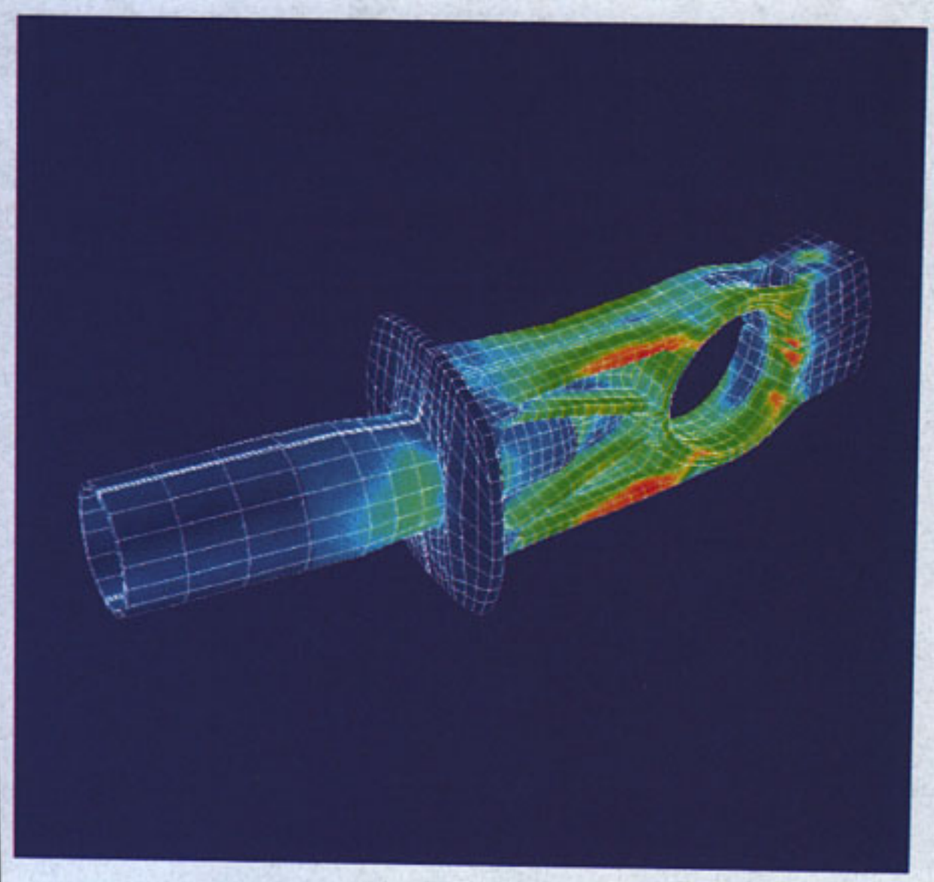

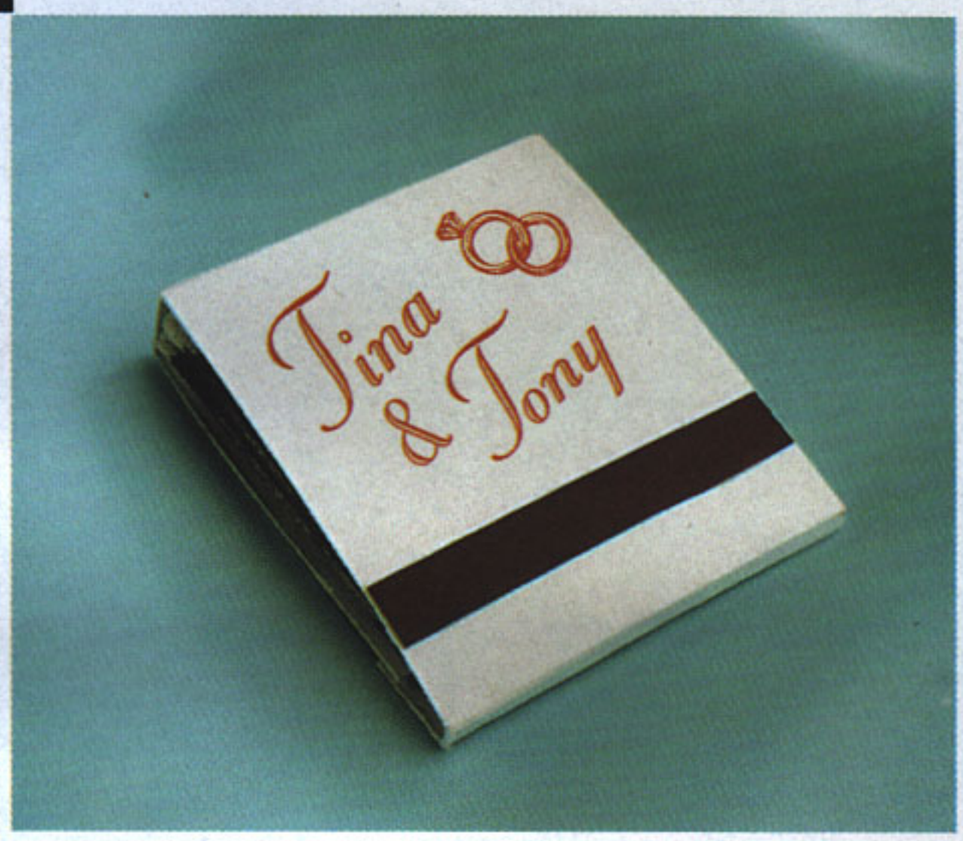

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This Just In....

Good evening, Mr. and Mrs. America and all the ships at sea. This just in...Once again we invoke Walter Winchell's famous opening line for another edition of "This Just In" for *IRIS Universe*. I've always been fascinated by media pioneers and Winchell was one of the great ones. Just as Winchell pioneered new forms of mass media from the 1930s through the 1950s, Silicon Graphics is blazing the trail of new media into the next century.

Eye on *i on*: One of those trailblazing efforts came to life in August with the debut of Silicon Graphics' new Internet-based magazine, *i on Visual Computing*. Published on the World Wide Web, *i on* offers a lively mix of articles, graphics, and neat little ditties about the people and technologies that are paving the information highway and driving the evolution of visual computing. "To demystify visual computing, we give readers access to the vision and technology of industry leaders," says Wendy Govier, *i on*'s editor-in-chief. "We take you behind the scenes and show you what's actually happening." The magazine has covered such exciting topics as pop star Graham Nash's and jazz great Herbie Hancock's use of real-time computer visuals for their stage performances, Steven Spielberg's Shoah project to catalog testimonials from Holocaust survivors, and video game clips from Rocket Science. Check it out on the Web at http://www.ion.sgi.com.

Author, Author!: Speaking of the World Wide Web, Silicon Graphics has launched a series of advanced new authoring tools to enhance the WebFORCE products. Leading the pack is WebSpace Author, a hot, next-generation authoring tool to create cool 3D virtual environments on the Web. WebSpace Author is a sophisticated, yet easy-to-use VRML (Virtual Reality Modeling Language) that provides all of the tools needed to add compelling , high-performance, 3D content to any Web site (can't wait to see what i on does with this). The software can import 3D models from the popular modeling programs, easily assemble models, and create links from 3D images on the screen to other Web content. But wait, there's more: Silicon Graphics also announced WebMagic Pro, a souped-up version of the world's first WYSIWYG HTML authoring tool. WebMagic Pro allows businesses to wow customers, competitors, and everyone else by creating incredible Web sites. Silicon Graphics is also offering Gauntlet, a leading firewall security option from Trusted Information Systems Inc. WebSpace Author, WebMagic Pro, and WebSpace navigator are being bundled with all WebFORCE Indy and Indigo^2 authoring systems. WebSpace Author and WebMagic Pro are also available free to WebFORCE owners who are members of Club WebFORCE.

Looking Forward: Alias/Wavefront chief Rob Burgess and Silicon Graphics' COO Tom Jermoluk kicked off SIGGRAPH '95 in Los Angeles with a preview of Alias/Wavefront's revolutionary product development initiative, dubbed Project Maya. "While the industry has made amazing advances over the years, we have reached a critical point where quantum leaps are necessary to provide the kind of expressive and extensible technology that artists, animators, and designers need and want," Burgess said. "Project Maya leverages our companies' combined experience in extending the limits of software for creative professionals." Project Maya is an innovative new architecture for creative software that will blow the roof off of current standards of productivity, user interface, and new computer graphics algorithms. Maya is expected to have a dramatic impact the on level of possible realism and therefore the use of computer graphics, the speed with which high-quality graphics can be produced,

and the creative experience of the artist using digital tools. The company expects to unveil its first products from this development initiative within a year. Alias/Wavefront, a Silicon Graphics subsidiary, also unveiled a new CAD visualization package, called Explore Vision, along with major releases of its flagship products, including Alias Animator 7.0, the entry-level solution for 3D animators; a new version of Alias Studio 7.0; the computer-aided industrial design program; AutoStudio 7.0 and Alias Designer 7.0.

Hey Buddy, wanna buy a computer? Silicon Graphics has launched a new two-tier distribution strategy to sell workstations and servers through Value-Added Resellers (VARs) and Value Added Dealers (VADs). To get this new distribution initiative off the ground (not that we're stretching the "launch" metaphor), Silicon Graphics has established a Master Reseller relationship with Access Graphics Inc., a leading distributor of UNIX-based client/server solutions to resellers. The two companies also lifted off a new program, dubbed ChannelPower, to deliver enhanced service and support to resellers.

Awards and Accolades: Kudos for Kurt Akeley, Silicon Graphics co-founder and chief engineer. Akeley was this year's recipient of the prestigious SIGGRAPH Achievement Award. The Association of Computing Machinery's Special Interest Group on Graphics recognized Akeley for his leadership in educating graphics professionals over the last 13 years. Akeley led the development of RealityEngine and RealityEngine^2 for the Onyx and POWER Onyx supercomputers. He also led the development of OpenGL and has authored numerous papers on graphics computing. Congrats Kurt...

Silicon Graphics has emerged as the leading provider of supercomputing solutions among the top 500 supercomputing sites, according to a survey conducted by the University of Mannheim in Germany. Since Mannheim's list was first published in 1993, Silicon Graphics presence in the top supercomputing sites has grown from zero to 128. Not bad...Silicon Graphics' OpenGL, the coolest graphics API for 2D and 3D, has won a couple of new converts. Hewlett-Packard Co., the nation's second largest computer company, and SunSoft Inc., the operating system subsidiary of Sun Microsystems Inc., have both licensed OpenGL. That brings to 34 the number of computer and software producers that are licensing the technology...Finally, at the International broadcasting Convention in Amsterdam, several leading video management, storage, and integration companies announced their support for the Silicon Graphics CHALLENGE line of media servers. That means a whole slew of hot new products are now and will soon be available for the CHALLENGE. The supporting companies include Viewgraphics, Louth Automation, Ciprico, Vangard Technology, and Columbine JDS.

National Data Lab : Silicon Graphics is teaming up with he National Center for Supercomputing Applications (NCSA) to set up a new National Data Laboratory. You may remember the folks at NCSA. They're the ones who produced the original Mosaic browser and almost single handedly launched the World Wide Web. The National Data Lab has nothing to do with Data the android that so many of us know and love from *Star Trek the Next Generation.* Housed at the NCSA headquarters at the University of Illinois the lab will develop and implement high-performance commercial computing applications. Up to now, NCSA has focused on virtual reality and data visualization for scientific data visualization. This new collaboration will carry them into commercial applications for parallel processing, high-performance databases and advanced data mining. That's a pretty hot area these days. The Gartner Group estimates that the commercial parallel computing market is growing at about 70 percent a year and it's expected to hit $5.3

billion by the end of 1998. The lab will develop intelligent algorithms to recognize and analyze patterns in commercial databases. This has some cool applications. It can help in the development of neural networks that mimic the human brain (though it's probably not as sophisticated as Data's positronic network of subdermal processors), and genetic algorithms that mimic the process of natural evolution. The lab will use network of Silicon Graphics high-end Onyx deskside supercomputers and CHALLENGE servers, connected to NCSA's hot 64-processor POWER CHALLENGEARRAY supercomputer.

MindShare: Silicon Graphics has taken another step to transform the way people share information on the Web. The company introduced MindShare OutBox, the first drag-and-drop desktop Web publishing tool for heterogeneous workgroup collaboration. Using OutBox, integrated with Silicon Graphics' WebMagic HTML editor and collaborative communication software, Indy and Indigo^2 users can quickly and easily generate Web pages that are hyper-linked to any data type easily accessed by PCs, Macintoshes or other Unix systems. Corporate users can then retrieve the information by using any industry standard Web browser. "Companies throughout the world have realized the vast potential of the World Wide Web as a powerful vehicle to tighten the communication gap between themselves and their customers," said Tom Furlong, vice president and general manager of Silicon Graphics' Digital Media Systems division. "With tools like MindShare OutBox, these companies can now use the Web to serve as a dynamic communications and collaboration medium within their own organizations."

The Wait is Over: Silicon Graphics has begun volume shipments of the much anticipated Indigo^2 IMPACT workstations as well as new workstations and servers based on the 250MHz Mips 4400 processor (wicked fast computers). You should remember the Indigo^2 IMPACT. Introduced in July, it is the only desktop graphics platform with both the world's fastest 3D graphics and fastest imaging performance (zoom!). Indigo^2 IMPACT boasts three times the 3D performance and as much as 100 times the complex visualization power as the Indigo^2 Extreme, which had been the world's fastest desktop workstation. Silicon Graphics is also shipping upgrades of the Indigo^2 workstations, Onyx graphics supercomputers and CHALLENGE servers with the 250 MHz Mips 4400 CPU. The CHALLENGE and Onyx systems with 4MB of secondary cache reach performance levels as high as 180.2 for SPECint and 177.5 for SPECfp.

Smart Choices: Europort-2, the European group of 32 consortia that's working to prove the performance and competitive advantages of parallel processing, has selected Silicon Graphics' POWER CHALLENGEARRAY multiprocessor supercomputer as an official parallel processing architecture. The consortia plans to port 38 large third-party and in-house serial codes to SMP and array architectures. Under the agreement, Europort-2 will use the 64-processor POWER CHALLENGEARRAY system at Silicon Graphics European Supercomputing Technology Center in Cortaillod, Switzerland to demonstrate the performance of parallelized applications in computational chemistry.

EdgeMark Systems: Silicon Graphics has selected EdgeMark systems, Inc. of Gaithersburg, Maryland, as the exclusive GSA schedule holder for its desktop computer products. Expecting to hire as many as 40 additionsl sales and technical professionals, EdgeMark, formerly Alpha Network Technologies, plans to relocate to Silver Spring, Maryland, in order to accomodate the new growth.

Unfortunately, I can't remember how Winchell used to end his broadcasts, or I'd use it here to sign off. But I'll end with the words of another broadcast pioneer: "And that's the way it is."

ADVERTISER INDEX

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November Through December 1995

4D SERIES COURSES	LOCATION* WEC	EEC	SEC	DEC	BEC	LAEC
Introduction to IRIX 4.5 days	Nov 27 Dec 18	Dec 11	Dec 4	Nov 27	Nov 27	N/A
Open GL Programming 1 4.5 days	Dec 11	N/A	N/A	Nov 13	N/A	N/A
Open GL Programming 2 4.5 days	Nov 27	N/A	N/A	Dec 18	N/A	N/A
IRIX IM Programming 4.0 days	N/A	Nov 6	N/A	N/A	N/A	N/A
Real Time Programming 4.5 days	Dec 11	N/A	Nov 6	N/A	N/A	N/A
Parallel Programming 4.5 days	Oct 23	Aug 21	Sep 18	N/A	N/A	N/A
ONYX Maintenance 10.0 days	Nov 27 Dec 11	Nov 27	N/A	Dec 4	N/A	N/A
Digital Media Programming 4.0 days	Dec 4	N/A	N/A	N/A	N/A	N/A
IRIS Performer 4.5 days	Nov 13	N/A	N/A	N/A	N/A	N/A
System Administration 5.X 4.5 days	Nov 6 Nov 13	Nov 27 Dec 18	Dec 11	Nov 6 Dec 4	Nov 13	Nov 27
Network Administration 1 4.5 days	Nov 13 Nov 27 Dec 11	Nov 13 Dec 4	N/A	N/A	Nov 6 Dec 11	N/A
Advanced System Administration 5.X 4.5 days	Nov 6 Dec 4	Nov 13 Dec 11	Nov 27	Nov 13	N/A	Nov 6
Open Inventor .5 days	Nov 13	N/A	N/A	N/A	N/A	N/A
ImageVision Library 2.0 days	Nov 13	N/A	N/A	N/A	N/A	N/A

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WEC--Western Education Center, Mountain View, CA.
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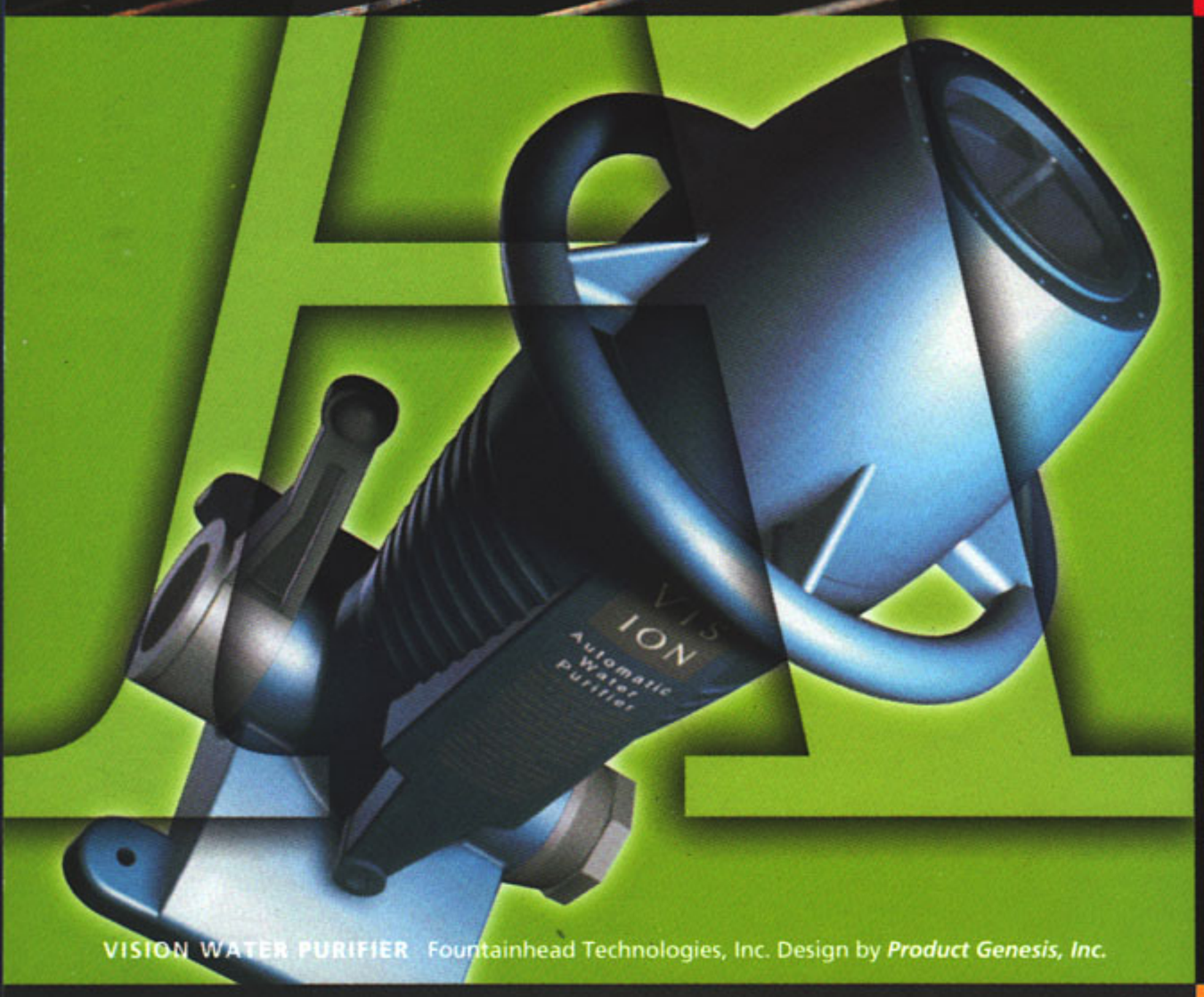

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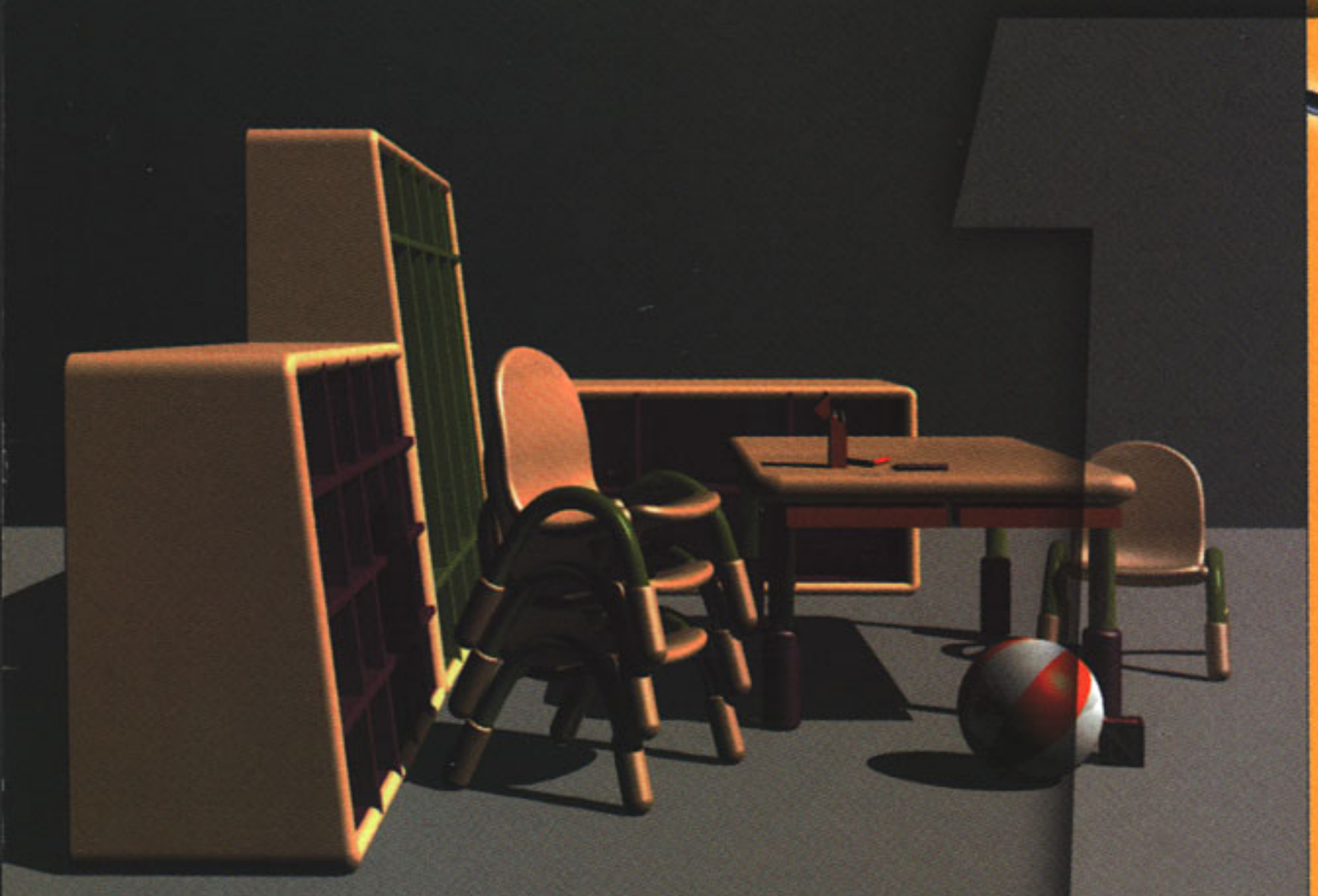

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